The information presented here reflects EPA's modeling of the Clear Skies Act of 2002. The Agency is in the process of updating this information to reflect modifications included in the Clear Skies Act of 2003. The revised information will be posted on the Agency's Clear Skies Web site (www.epa.gov/clearskies) as soon as possible.

TECHNICAL ADDENDUM: METHODOLOGIES FOR THE BENEFIT ANALYSIS OF THE CLEAR SKIES INITIATIVE

September 2002

I. INTRODUCTION

Background

The Need for Multi-pollutant Legislation

In the United States, power generation is responsible for 63% of sulfur dioxide (SO_2), 22% of nitrogen oxides (NO_x), and 37% of man-made mercury released to the environment. Once released, these pollutants together with their atmospheric transformation products (e.g. ozone and fine particles) can travel long distances before being deposited. Environmental and public health problems resulting from power generation emissions include:

- Cardiovascular and respiratory conditions associated with exposure to fine particles (PM) and ozone;
- Visibility impairment associated with regional haze;
- Acidification of surface waters and forest ecosystems;
- Ecosystem and public health effects associated with the accumulation of mercury in fish and other wildlife;
- Acidic damage to cultural monuments and other materials;
- Ozone damage to forested ecosystems; and
- Eutrophication in coastal areas.

While the current Clean Air Act has played a role in significantly improving some of these issues, additional reductions in the emissions of SO_2, NO_x, and mercury are necessary to address persistent public health and environmental problems. Because of the regional and global scale of these pollutants, individual states or localities experiencing the environmental effects cannot always control them. In addition, current law tends to address each environmental problem independently, even if one pollutant contributes to several problems. To more effectively address the environmental problems caused by power generation, there is a need for a national program that would take advantage of synergies of controlling multiple pollutants at once.

The Clear Skies Act

On February 14, 2002, the President announced the Clear Skies Initiative, a proposal to reduce emissions from electric power generating sources. The proposal was embodied in legislative form as the Clear Skies Act, which was introduced in the House of Representatives as H.R.5266 and in the Senate as S.2815 in July 2002. For the purpose of the analyses presented here, the central features examined in the Initiative are identical to those contained in the Act.

The Clear Skies Act would reduce emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury from fossil fuel-fired combustion units by approximately 70% from current levels.[1] These mandatory emission reductions would be achieved through a cap and trade

[1] The Clear Skies Act would cut sulfur dioxide (SO2) emissions by 73 percent, from current emissions of 11 million tons to caps of 4.5 million tons in 2010 and 3 million tons in 2018. It would cut emissions of nitrogen oxides (NOx) by 67 percent, from current emissions of 5 million tons

program, modeled on the current Acid Rain Program for SO_2. Federally enforceable emissions limits, or national caps, for each pollutant would be established. Sources would be allowed to transfer these authorized emission limits among themselves to achieve the required reductions for all three pollutants at the lowest overall cost. This proposal would alleviate many of the remaining environmental and health problems associated with power generation.

This document reports the methods and results of an analysis of the environmental and health benefits of the Clear Skies Act. It presents quantitative estimates of the health improvements and monetary benefits that would be achieved by this proposal.

Summary of the Benefits Analysis Methods and Results

The Clear Skies Act would provide significant benefits to public health and the environment, whether expressed as health and environmental improvements or as monetized benefits. These include prolonging thousands of lives and reducing tens of thousands to millions of cases in other indicators of adverse health effects, such as work loss days, restricted activity days, and days with asthma attacks. Environmental benefits include significant increases in visibility and substantial improvements in chronically acidic conditions in lakes in the Northeastern US. Based on emissions reductions that would start well before 2010 and the expected increase in benefits between 2010 and 2020, the cumulative health benefits of the program across the next two decades would be significant. The key results of this analysis of the Clear Skies Act are summarized in Exhibit 1.

Section II (Analytical Approach) discusses the analytic framework used in conducting this assessment, which includes scenario development, emissions modeling, air quality modeling, human health and visibility effects estimation, economic valuation, and adjustments for income growth and benefits aggregation.

As depicted in Exhibit 1, we have used two approaches to provide benefits in health and environmental effects and in monetary terms. While there is a substantial difference in the specific estimates, both approaches show that the monetary benefits of the Clear Skies Act are well in excess of the estimated costs of $3.7 billion in 2010 and $6.5 billion in 2020.[2]

The first approach presented, the Base Estimate, is a peer-reviewed method developed for previous risk and benefit-cost assessments carried out by the Environmental Protection Agency. It is the method used in the regulatory assessments of the Heavy Duty Diesel and Tier II Rules and the Section 812 Report to Congress. Following the approach of these earlier assessments, along with the results of the Base Estimate, we present various sensitivity analyses on the Base Estimate that alter select subsets of variables; these sensitivity analyses yield results as much as 42 percent lower to over 180 percent higher. By far, the largest component of these monetized benefits is related to premature mortality from long-term exposure to particulate matter ($41 billion and $89 billion in 2010 and 2020, respectively), followed by chronic bronchitis ($1.5 billion and $3.2 billion in 2010 and 2020, respectively).

to caps of 2.1 million tons in 2008 and 1.7 million tons in 2018. Mercury emissions would be reduced by 69 percent, from current emissions of 48 tons to caps of 26 tons in 2010 and 15 tons in 2018.

[2] Detailed information on the costs of Clear Skies can be found in the Clear Skies Act Analytical Support Package (2002).

In order to provide some insight into the potential importance of the key elements underlying estimates of the benefits of reducing SOx and NOx emissions, we developed an Alternative Estimate using different choices of data, methods, and assumptions that are detailed in Section II (Analytical Approach). **[Please see Addendum 1 for an updated Alternative Estimate as of May 2003].** As indicated in Exhibit 1, the differences between the Alternative and Base Estimates are found in the estimation of the impact of fine particle reductions on premature mortality and the valuation of reducing the risk of premature mortality and the risk of chronic bronchitis. The Alternative Estimate of the impact of fine particle reductions on premature mortality relies on recent scientific studies finding an association between increased mortality and short-term (days to weeks) exposure to particulate matter, while the Base Estimate relies on a recent reanalysis of earlier studies that found associations between long-term exposure to fine particles and increased mortality. The Alternative approach also uses different data to value reductions in the risk of premature mortality and chronic bronchitis and makes adjustments relating to the health status and potential longevity of the populations most likely affected by PM. Even using the more conservative assumptions of this Alternative, the benefits of Clear Skies still outweigh the projected costs of the proposal.

All such benefit estimates are subject to a number of assumptions and uncertainties, which are discussed in Section III (Major Uncertainties in the Benefits Analysis) of this report. For example key assumptions underlying the Base and Alternative Estimates for the mortality category include the following: (1) Inhalation of fine particles is causally associated with premature death at concentrations near those experienced by most Americans on a daily basis. While biological mechanisms for this effect have not yet been definitively established, the weight of the available epidemiological evidence supports an assumption of causality. (2) All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because fine particles from power plant emissions are chemically different from directly emitted fine particles from both mobile sources and other industrial facilities, but no clear scientific grounds exist for supporting differential effects estimates by particle type. (3) The concentration-response function for fine particles is approximately linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of particulate matter, including both regions that are in attainment with fine particle standard and those that do not meet the standard. (4) The forecasts for future emissions and associated air quality modeling are valid. Although recognizing the difficulties, assumptions and inherent uncertainties in the overall enterprise, these analyses are based on peer-reviewed scientific literature and up-to-date assessment tools, and we believe the results are highly useful in assessing this proposal.

In addition to the quantified and monetized benefits summarized above, there are a number of additional categories are not currently amenable to quantification or valuation. These include: the health and environmental benefits of reducing mercury accumulation in fish and other wildlife; reduced acid and particulate deposition damage to cultural monuments and other materials; reduced ozone effects on forested ecosystems; and environmental benefits due to reductions of impacts of acidification in lakes and streams and eutrophication in coastal areas. Additionally, we have not quantified a number of known or suspected health effects linked with PM and ozone for which appropriate concentration-response functions are not available or which do not provide easily interpretable outcomes (i.e. changes in forced expiratory volume (FEV1)).

As a result, both the Base and Alternative monetized benefits estimates underestimate the total benefits attributable to the Clear Skies Act.

Exhibit 1
Summary of Results: The Estimated PM and Ozone-Related Benefits of the Clear Skies Act in 2010 and 2020[3]

	Base Estimate		Alternative Estimate	
	2010		2010	
Endpoint	Cases Avoided	1999$ (Millions)	Cases Avoided	1999$ (Millions)
Premature Mortality	6,400	$41,400* $38,900**	3,800	$4,400* $5,100**
Chronic Bronchitis	3,900	$1,500	3,900	$420
Hospitalization / ER Visits	6,300	$69	6,300	$69
Minor Respiratory Illness and Symptoms	8,000,000	$450	8,000,000	$450
Welfare Benefits	--	$1000	--	$1000
Total		**$44,000*** **$41,500****		**$6,300*** **$7,000****

	Base Estimate		Alternative Estimate	
	2020		2020	
Endpoint	Cases Avoided	1999$ (Millions)	Cases Avoided	1999$ (Millions)
Premature Mortality	11,900	$88,900* $83,500**	7,200	$9,400* $10,900**
Chronic Bronchitis	7,400	$3,200	7,400	$790
Hospitalization / ER Visits	11,900	$130	11,900	$130
Minor Respiratory Illness and Symptoms	15,100,000	$860	15,100,000	$860
Welfare Benefits	--	$3,000	--	$3,000
Total		**$96,000*** **$90,600****		**$14,200*** **$15,700****

* Results calculated using three percent discount rate as recommended by EPA's *Guidelines for Economic Analysis* (US EPA, 2000a).
** Results calculated using seven percent discount rate as recommended by OMB Circular A-94 (OMB, 1992).

[3] The two sets of estimates depicted in this table reflect alternative assumptions and analytical approaches regarding quantifying and evaluating the effects of airborne particles on public health. All estimates assume that particles are causally associated with health effects, and that all components have the same toxicity. Linear concentration-response relationships between PM and all health effects are assumed, indicating that reductions in PM have the same impact on health outcomes regardless of the absolute level of PM in a given location. The Base Estimate relies on estimates of the potential cumulative effect of long-term exposure to particles, while the Alternative Estimate presumes that PM effects are limited to those that accumulate over much shorter time periods. The Alternative Estimate also uses different approaches to value health effects damages. All such estimates are subject to a number of assumptions and uncertainties. It is of note that, based on recent preliminary findings from the Health Effects Institute, the magnitude of mortality from short-tern exposure (Alternative Estimate) and hospital/ER admissions estimates (both estimates) may be under or overestimated.

II. ANALYTICAL APPROACH

The framework for the Clear Skies Act benefits analysis is the same as that used in three recent state-of-the-art EPA regulatory analyses: the Section 812 Prospective Analysis (U.S. EPA, 1999a); the Tier II motor vehicle/gasoline sulfur rules Regulatory Impact Analysis (RIA) (U.S. EPA, 1999b); and the Heavy-Duty Engine/Diesel Fuel RIA (U.S. EPA, 2000b). The analysis uses the same health effect and valuation functions employed in the most recent of these analyses, the Heavy-Duty Engine/Diesel Fuel RIA. The analytical approach can be described as a sequence of six steps, summarized below and described in detail later in this report. These steps, listed in order of completion, are:

1. Scenario development
2. Emissions modeling
3. Air quality modeling
4. Human health and visibility effects estimation
5. Economic valuation
6. Adjustments for income growth and benefits aggregation

Exhibit 2 outlines the analytical framework used to study the benefits of the Clear Skies Act. The first step in the benefits analysis is the specification of the regulatory scenarios that will be evaluated. Typically, an analysis will include a baseline scenario that simulates future conditions in the absence of the proposed regulation and one or more control scenarios that simulate conditions under the regulations being evaluated. The benefits of a proposed regulation are then estimated as the difference in benefit outcomes (e.g., adverse health effects) between the control and baseline scenarios. For this analysis, the baseline scenarios for 2010 and 2020 assume no additional emissions control regulation beyond the continuing effects of Title IV of the Clean Air Act Amendments, the NO_x SIP Call, and other promulgated federal rules issued under the Clean Air Act. For each year (2010 and 2020), our analysis evaluates a single control scenario, as described below.

After scenario development, the second step of the benefits analysis is the estimation of the effect of the Clear Skies Act on emissions sources. We generated emissions estimates for the baseline by projecting changes in emissions under the baseline case for 2010 and 2020. We generated emissions estimates for the Clear Skies Act control scenario using the same set of economic activity projections as the baseline but with additional emissions controls consistent with the Clear Skies Act caps. Emissions inputs were derived from the 1996 NTI and the 1996 NEI. In addition, emissions inventories prepared for the Heavy-Duty Diesel Engine rulemaking were the basis for future year emissions projections. The Integrated Planning Model (IPM) was used to derive all future projections of electricity generation source emissions.

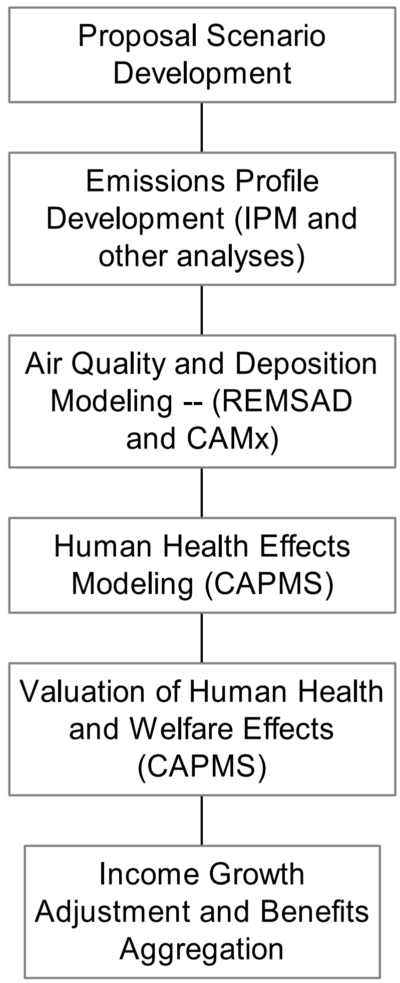
After the emissions inventories are developed, they are translated into estimates of future-year air quality conditions under each scenario. We employed two sophisticated computer models, the Regulatory Modeling System for Aerosols and Deposition (REMSAD) and the Comprehensive Air Quality Model with Extensions (CAMx) to estimate changes to the concentration of particulate matter and ozone, respectively, resulting from the Clear Skies Act. The REMSAD model was also used to estimate changes in visibility associated with those changes in particulate matter concentrations and to estimate changes in deposition of sulfur, nitrogen, and mercury.

The air quality modeling results serve as inputs to a modeling system that translates air quality changes to changes in health outcomes (e.g., premature mortality, emergency room visits) through the use of concentration-response functions. Scientific literature on the health effects of air pollutants provides the source of these concentration-response functions. At this point, we derive estimates of the differences between the two scenarios in terms of incidences of a range of human health effects that are associated with exposure to ambient particulate matter and ozone.

In the next step, we use economic valuation models or coefficients to estimate a dollar value for the reduced incidence of those adverse effects amenable to monetization. For example, analysis of estimates derived from the economic literature provides an estimate of the value of reductions in mortality risk. Finally, we adjust the benefit values for expected income growth through 2010 and 2020 and aggregate the benefits to the appropriate geographic level.

As noted in Section I (Introduction), we present Base and Alternative estimates for mortality and chronic bronchitis benefits. The different methodologies and assumptions for these approaches are discussed in separate subsections in the effects estimation and valuation sections below.

Exhibit 2
Analytic Sequence for
Multi-Emissions Reduction
Proposal Benefits Analysis



Baseline and Regulatory Scenario Development

This analysis looks at the impacts of the multi-pollutant reductions that are part of the Clear Skies Act for two future target years, 2010 and 2020. Avoided health effects and visibility improvements are quantified by comparing two scenarios:

(1) A baseline scenario (Base Case) that reflects the continuing effects of Title IV of the Clean Air Act Amendments (the Acid Rain Program) as well as other promulgated federal rules issued under Clean Air Act authority that are expected to affect Electric Generating Units (EGUs) and other sources of emissions (e.g. the NO_x SIP call and the Tier II and Heavy Duty Diesel Rules for mobile sources).

(2) A scenario that reflects full implementation of the Clear Skies Act in the target year.

Emissions Profile Development

Emissions Inventories

Emission inventories were developed to support the benefits analysis for the Clear Skies Act. Emissions profiles were generated for the following cases: 1996 Base Year, 2010 Base Case, 2010 Clear Skies, 2020 Base Case, and 2020 Clear Skies.

These national inventories were prepared for all 50 States at the county level for mobile highway and non-road sources. They were prepared for the 48 contiguous states at the county-level for electric generating unit (EGU), non-EGU point, and stationary area sources. The approach used to create inventories was the same as that used for the Heavy-Duty Engine (HDE) Rulemaking analysis (US EPA, 2000d) with modifications to reflect emission and modeling advances since that analysis.[4]

Power generation emissions of SOx and NOx for each of the scenarios is presented in The Clear Skies Act: Technical Support Package. Exhibit 3 presents total national emissions of NO_x and SO_2 from all sectors, including power.

[4] This approach was documented and can be located at http://www.epa.gov/otaq/hdmodels.htm.

Exhibit 3
National SOx and NOx Emissions Projections for Base and Clear Skies Scenarios (million tons)

Scenario	SO_2 Emissions, All sectors	NOx Emissions, All sectors
1996 Base Year	18.8	26.0
2010 Base Case	16.0	19.4
2010 Clear Skies	13.1	17.3
2020 Base Case	15.8	16.1
2020 Clear Skies	10.9	13.6

The 1996 Base Year inventory was used to project future emissions under the Base Case and differences between the Base Case and the Clear Skies Act. It was constructed using existing emissions inventories created for various recent rulemaking activities. For criteria pollutants, the 1996 National Emissions Inventory (NEI) used for the Heavy Duty Diesel vehicle rulemaking was used. For mercury, the 1996 National Toxics Inventory was modified based on the 1999 information collection effort for coal utilities and the 2002 MACT implementation for medical waste incinerators, and the 2000 MACT implementation for municipal waste combustors was used.

For the 2010 and 2020 Base Cases, emissions under current regulations with economic and population growth were projected. The electric utility portion was developed using the Integrated Planning Model (IPM). IPM projects power sector emissions under Title IV of the 1990 Clean Air Act Amendments (The Acid Rain Program), which caps SO_2 emissions at 8.95 million tons/year beginning in 2010. In addition, IPM's projections for electric utilities under the Base Case include the NO_X SIP Call with a cap on summertime NO_X emissions in SIP Call states in 2004 (based on 0.15 lb/mmBtu from 2001) and state-imposed NO_X caps in Texas, Connecticut, and Missouri. This case also includes no controls on mercury emissions from power generation. The emissions inventory for the Base Case also includes Tier II and Heavy Duty Diesel Rules for mobile sources. The uncertainty about how these mobile source rules will be implemented in the future contributes to uncertainty in both the Base Case and the Clear Skies Act profile.

The 2010 and 2020 Clear Skies Act profile includes a 4.5 million ton/year cap on EGUs beginning in 2010 for SO_2 emissions, which will be lowered to a 3 million ton cap in 2018; a 2.1 million ton/yr cap beginning in 2008 for NO_X emissions, which will be lowered to a 1.7 million ton cap in 2018; and a 26 ton/yr cap beginning in 2010 for mercury emissions, which will be lowered to a 15 ton cap in 2018. Because sources can reduce emissions early, earn allowances for these actions, and use the allowances later, actual emissions are projected to be higher than the cap in the first years of each cap.

The Integrated Planning Model (IPM)

The Integrated Planning Model (IPM) predicts future emissions outputs from EGUs affected by the Clear Skies Act. These outputs are used to develop the emissions inventories.

IPM is a linear programming model of the electricity sector that finds the most efficient (i.e. least cost) approach to operating the electric power system over a given time period subject to specific constraints (e.g. pollution caps or transmission limitations). The model, which was developed for EPA by ICF Resources, Inc., selects investment strategies given the cost and performance characteristics of available options, forecasts of customer demand for electricity, and reliability criteria. System dispatch, which determines the proper and most efficient use of the existing and new resources available to utilities and their customers, is optimized given the resource mix, unit operating characteristics, and fuel and other costs. Unit and system operating constraints provide system-specific realism to the outputs of the model.

The IPM is dynamic; it has the capability to use forecasts of future conditions, requirements, and option characteristics to make decisions for the present. This ability replicates, to the extent possible, the perspective of utility managers, regulatory personnel, and the public in reviewing important investment options for the utility industry and electricity consumers. Decisions are made based on minimizing the net present value of capital and operating costs over the full planning horizon. IPM also models a variety of environmental market mechanisms, such as emissions caps, allowances, trading, and banking.[5]

Air Quality and Deposition Modeling

Air quality modeling is a critical analytical step that provides the link between emissions changes and the physical effects that affect human health and the environment. This step of the analysis employs complex computer models that simulate the transport and transformation of emitted pollutants in the atmosphere. The results of these model runs are predictions of pollutant concentrations under each of the emission control scenarios specified above. These predicted concentrations are then used as inputs to the human health effect estimation model discussed in the next section.

Air quality modelers face two key challenges in attempting to translate emission inventories into pollutant concentrations. First, they must model the dispersion and transport of pollutants through the atmosphere. Second, they must model pertinent atmospheric chemistry and other pollutant transformation and removal processes. These challenges are particularly difficult for those pollutants that are not emitted directly but instead form through secondary processes. Ozone is the best example; it forms in the atmosphere through a series of complex, non-linear chemical interactions of precursor pollutants, particularly certain classes of volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Modelers face similar challenges when

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[5] Complete documentation of the IPM model can be found at http://www.epa.gov/airmarkt/epa-ipm/index.html#documentation.

estimating PM concentrations. Atmospheric transformation of gaseous sulfur dioxide and nitrogen oxides to particulate sulfates and nitrates, respectively, contributes significantly to ambient concentrations of fine particulate matter. In addition to recognizing the complex atmospheric chemistry relevant for some pollutants, air quality modelers also must deal with uncertainties associated with variable meteorology and the spatial and temporal distribution of emissions.

Air quality modelers and researchers have responded to the need for scientifically valid and reliable estimates of air quality changes by developing a number of sophisticated atmospheric dispersion and transformation models. Some of these models have been employed in support of the development of federal clean air programs, national assessment studies, State Implementation Plans (SIPs), and individual air toxic source risk assessments. In this analysis, we used two of these well-established models, the Regional Modeling System for Aerosols and Deposition (REMSAD) and the Comprehensive Air Quality Model with Extensions (CAMx), to develop a picture of future changes in air quality resulting from the implementation of the Clear Skies Act.

Regional Modeling System for Aerosols and Deposition (REMSAD)

The change in PM concentrations due to the Clear Skies Act was modeled using the Regional Modeling System for Aerosols and Deposition (REMSAD). REMSAD was also used to estimate the changes in visibility and deposition of mercury, nitrogen, and sulfur. REMSAD is a three-dimensional, grid-based Eulerian air quality model designed to simulate long-term (e.g., annual) concentrations and deposition fluxes of atmospheric pollutants over large spatial scales (e.g., over the contiguous U.S.). Air pollution issues meant to be addressed by REMSAD include long-term $PM_{2.5}$ ambient concentrations; visibility; ambient concentrations and deposition fluxes of several hazardous air pollutants, including mercury; deposition fluxes of nutrient nitrogen; and deposition of acids such as sulfuric acid and nitric acid.

REMSAD has been developed under funding from the U.S. Environmental Protection Agency over the past five years. REMSAD consists of three components: (1) a meteorological data pre-processor; (2) the core aerosol and toxic deposition model (ATDM); and (3) post-processing programs. The horizontal grid size can be on the order of a few kilometers (km) for an urban-scale simulation up to about 100 km for a continental-scale simulation. For large-scale simulations, one-way nesting of fine and coarse grids can be performed to allow simulation of sensitive areas with strong pollution spatial gradients using a fine grid resolution. The vertical structure of REMSAD covers the whole troposphere from the surface up to about 15 km. The physical and chemical processes simulated by REMSAD include emissions of pollutants from surface and elevated sources, advective transport, horizontal turbulent diffusion, vertical mixing via turbulent diffusion and convective transport, cloud processes, gas-phase and aqueous-phase chemistry, $PM_{2.5}$ formation, dry deposition and wet deposition.

Version 6.40 of REMSAD was employed for this analysis. Previous versions of REMSAD have been used to estimate PM for EPA's Heavy Duty Engine Diesel Fuel Rule and for the first Section 812 Prospective Analysis. REMSAD Version 6.40 includes improvements that address comments EPA obtained during the 1999 peer review of REMSAD Version 4.1

(Seigneur et al., 1999), including improved treatment of ammonium/nitrate/sulfate equilibrium, inclusion of additional aqueous sulfate formation pathways, and expanded treatment of mercury chemistry (ICF Consulting, 2001).

The REMSAD modeling domain selected for the Clear Skies Act consists of 36 km x 36 km grid cells covering the 48-contiguous United States, and REMSAD can perform a full-year simulation, generating predictions of hourly PM concentrations (including both $PM_{2.5}$ component species and PM_{10}) at each grid cell. These hourly predictions form the basis for direct calculation of daily and annual PM air quality metrics (e.g., annual mean PM concentration) as inputs to the health and welfare C-R functions of the benefits analysis. REMSAD also gives visibility, which is used as an input into the visibility damage function.

For this benefits analysis, we applied REMSAD to the entire U.S. for four future-year scenarios: a 2010 Base Case, a 2020 Base Case, a 2010 Clear Skies Act Case, and a 2020 Clear Skies Act Case. The difference in REMSAD-modeled PM concentrations for these scenarios represents the expected change in PM due to the emission controls under the Clear Skies Act.

Comprehensive Air Quality Model with Extensions (CAMx)

We modeled changes in ozone in the eastern U.S. using the Comprehensive Air Quality Model with Extensions (CAMx). CAMx is an Eulerian photochemical dispersion model designed to assess both gaseous and particulate air pollution over many scales, from urban to super-regional. The model estimates concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect ozone formation. The latest version of the model, CAMx 3.10, provides full support for parallel processing for increased computational performance, as well as new algorithms for gas phase chemistry (CAMx v3.10 User's Guide, April 2002).

The modeling domain for this analysis encompasses most of the eastern U.S., bounded on the east by the 67 degrees west longitude and on the west by the 99 degrees west longitude. Ozone modeling is only done for the East because there is very little confidence in the application of this model to the West. The horizontal resolution for the outer grid is approximately 36 km. The horizontal resolution for the inner grid is approximately 12 km. The vertical resolution for both grids consists of nine layers. The top of the modeling domain is 4000 meters above ground level. Recognizing the relationship between grid cell resolution and the certainty of results, we sought to estimate pollutant concentrations in more populated areas using higher resolution models. Similarly, we used an intermediate resolution grid (12 km x 12 km) to model ozone in "inner OTAG" states where population density is high and ozone transport is a major problem.[6] This approach makes CAMx well suited to estimate effects based on a range of ozone averaging times, an important capability for benefits assessment applications.

This study extracted hourly, surface-layer ozone concentrations for each grid-cell from the standard CAMx output file containing hourly average ozone values. These model predictions are used in conjunction with the observed concentrations obtained from the Aerometric

[6] The Ozone Transport Assessment Group (OTAG) consists of the 37 easternmost states and the District of Columbia. The "inner OTAG" region is comprised of the more eastern (and more populated) states within the OTAG domain.

Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[7,8] The predicted changes in ozone concentrations from the Base Case to the Clear Skies Act serve as inputs to the health and welfare C-R functions of the benefits analysis, i.e., the Criteria Air Pollutant Modeling System (CAPMS).

In order to estimate ozone-related health and welfare effects for the eastern U.S., full-season ozone data are required for every CAPMS grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in the modeling domain in two steps: (1) we combine monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of 8 km by 8 km population grid-cells, as will be described in the Human Health and Environmental Effects Modeling section, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily average. [9, 10] For the analysis of ozone impacts on agriculture, we use a similar approach except air quality is interpolated to county centroids as opposed to population grid-cells. We report ozone concentrations as a cumulative index called the SUM06. The SUM06 is the sum of the ozone concentrations for every hour that exceeds 0.06 parts per million (ppm) within a 12-hour period from 8 am to 8 pm in the months of May to September. These methods are described in detail in the Heavy Duty Engine/Diesel Fuel RIA (USEPA, 2000b).

Human Health and Environmental Effects Modeling

As part of the evaluation of the effects of various scenarios concerning SO_2 and NO_x emissions, we have identified and, where possible, developed quantitative, monetized estimates of these health benefits. This section describes the first step in this process, the estimation of changes in the incidence of adverse health effects. Our analysis also looked at several environmental endpoints, including the benefits associated with visibility improvements, ozone damage to agriculture, and changes in acidification in lakes and streams in the East.

Exhibit 4 provides a list of the health effects for which we estimate quantified benefits as part of our analysis plus a list of the health effects for which we are unable to quantify benefits at this time. The unquantified benefits for ozone and PM fall into two categories: (1) those for which the scientific literature does not provide an established Concentration-Response (C-R) function capable of estimating health effects with reasonable certainty and (2) those effects that may double-count benefits (e.g., hospital admissions for specific cardiovascular illnesses). The direct health effects of nitrogen oxide gases and sulfur dioxide gases are also unquantified. Although C-R functions are available to estimate health effects of exposure to nitrogen oxides

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[7] The ozone season for this analysis is defined as the 5-month period from May to September; however, to estimate certain crop yield benefits, the modeling results were extended to include months outside the 5-month ozone season.

[8] Based on AIRS, there were 949 ozone monitors with sufficient data, i.e., at least 9 hourly observations per day (8 am to 8 pm) in a given season.

[9] The 8 km grid squares contain the population data used in the health benefits analysis model, CAPMS. See Section C of this chapter for a discussion of this model.

[10] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation (See Abt Associates (2000) for a more detailed description).

and sulfur dioxide gases, these effects were not estimated in this analysis because of modeling and resource limitations. The health and environmental effects of mercury exposure are also not quantified. EPA is currently investigating methods to quantify and monetize the human health related benefits of reductions in air emissions of mercury. However, there are still major gaps in the science of mercury fate, transport, and transformation that make such an assessment difficult at time. Methods for mercury benefits analyses are still under development and do not yet provide a means to estimate the mercury-related benefits of the Clear Skies Act.

Exhibit 4
Human Health Effects of Air Pollutants

Pollutant	Quantified Health Effects	Unquantified Health Effects
Ozone	Minor restricted activity days Hospital admissions- Respiratory and Cardiovascular Emergency room visits for asthma Asthma attacks	Mortality Increased airway responsiveness to stimuli Inflammation in the lung Chronic respiratory damage / Premature aging of the lungs Acute inflammation and respiratory cell damage Increased susceptibility to respiratory infection Respiratory symptoms Chronic asthma (new cases) Non-asthma respiratory emergency room visits
Particulate Matter (PM_{10}, $PM_{2.5}$)	Chronic Premature Mortality* Acute Premature Mortality ‡* Bronchitis – Chronic and Acute Hospital admissions - Respiratory and Cardiovascular Emergency room visits for asthma Lower and Upper respiratory illness Asthma Attacks Respiratory symptoms Minor restricted activity days** Days of work loss	Changes in pulmonary function Neonatal mortality Low birth weight Chronic respiratory diseases other than chronic bronchitis Morphological changes Altered host defense mechanisms Moderate or worse asthma status (asthmatics) Shortness of breath Lung cancer Acute myocardial infarction Cardiac arrhythmias School absence days
Mercury		Neurological disorders Learning disabilities Retarded development Cerebral palsy Cardiovascular effects Altered blood pressure regulation Increased heart rate variability Myocardial infarctions Damage to the immune system Altered renal function and renal hypertrophy Reproductive effects
Nitrogen Oxides		Respiratory illness Hospital Admissions - All Respiratory and All Cardiovascular Non-asthma respiratory emergency room visits Increased airway responsiveness to stimuli Chronic respiratory damage / Premature aging of the lungs Inflammation of the lung Increased susceptibility to respiratory infection Acute inflammation and respiratory cell damage
Sulfur Dioxide		Hospital Admissions - All Respiratory and All Cardiovascular In exercising asthmatics: Chest tightness, Shortness of breath, or Wheezing Non-asthma respiratory emergency room visits Changes in pulmonary function Respiratory symptoms in non-asthmatics

‡ Quantified as an alternative or supplemental calculation. Current uncertainties in our understanding of these effects and/or concern about double counting of benefits do not support including these quantitative estimates in the primary benefits estimate. Moderate or Worse Asthma Status is not included in Primary Estimate due to concerns of double-counting other asthma endpoints.

* This analysis estimates avoided mortality using PM as an indicator of the criteria air pollutant mix to which individuals were exposed.

** Minor restricted activity days are estimated excluding asthma attacks to avoid double counting.

Exhibit 5 provides a list of the ecological effects associated with the emissions targeted by Clear Skies. As stated earlier, most of these effects have not been quantified as part of our analysis, due to data or modeling limitations. We have, however, monetized effects of changes in ambient ozone on some agricultural production and changes in particulate matter on visibility.

Exhibit 5
Ecological Effects of Air Pollutants

Pollutant	Quantified Effects	Unquantified Effects
Particulate Matter (PM_{10}, $PM_{2.5}$)	Recreational visibility in Class I areas in California, the Southwest, and the Southwest	Recreational visibility for Class I areas in other parts of the U.S. Residential visibility
Ozone	Impacts to agriculture (e.g., reduced crop yields)	Impacts on commercial timber sales Ozone impacts on carbon sequestration in commercial timber
Acidic Deposition		Impacts to recreational freshwater fishing Impacts to commercial forests (e.g., timber, non-timber forest products) Impacts to commercial freshwater fishing Watershed damages (water filtration flood control) Impacts to recreation in terrestrial ecosystems (e.g. forest aesthetics, nature study) Reduced existence value and option values for non-acidified ecosystems (e.g. biodiversity values)
Nitrogen Deposition		Impacts to commercial fishing, agriculture, and forests Watershed damages (water filtration, flood control) Impacts to recreation in estuarine ecosystems (e.g. recreational fishing, aesthetics, nature study) Reduced existence value and option values for non-eutrophied ecosystems (e.g. biodiversity values)
Mercury Deposition		Impacts on birds and mammals (e.g. reproductive effects) Impacts to commercial, subsistence, and recreational fishing Reduced existence value and option values for ecosystems without accumulated mercury (e.g. biodiversity values)

To estimate health benefits from the Clear Skies Act, we used the same general approach used in recent major OAR regulatory analyses (U.S. EPA, 1999a, 1999b and 2000b). This approach takes the estimates of changes in ambient pollutant concentrations predicted by air quality modeling for each scenario (relative to the baseline scenario) and converts them into estimates of changes in the incidence of adverse health effects using concentration-response (C-R) functions. The model we use to generate these estimates is the Criteria Air Pollutant Modeling System (CAPMS).

We calculated the benefits attributable to the Clear Skies Act as the change in incidence of adverse health effects between the control and baseline scenarios. CAPMS estimates incidence changes for each health effect within 8 km x 8 km grid cells covering the contiguous U.S. and generates national health benefits estimates by summing the annual incidence change for each effect across all grid cells. CAPMS uses C-R functions specific to each health effect to calculate incidences in each grid cell. C-R functions are equations that relate the change in the number of individuals in a population exhibiting a "response" (in this case an adverse health effect such as respiratory disease) to a change in pollutant concentration experienced by that population. In general, the C-R functions used in CAPMS require four input values: (1) the grid-cell-specific change in pollutant concentration; (2) the grid-cell affected population (i.e. asthmatic children); (3) the baseline incidence rate of the health effects; and (4) an estimate of the change in the number of individuals that suffer an adverse health effect per unit change in air quality. Both the form of the C-R function and the fourth input value are derived from epidemiological studies in the scientific literature that link pollutant exposures with adverse health effects.

In addition to our national benefits results, we generated regional estimates of the benefits of the Clear Skies Act using the same benefits estimation procedure used to generate the national estimates. The REMSAD and CAMx air quality models provide information on the improvements in ambient air concentrations throughout the country within 36 km by 36 km gridboxes. This information is used in subsequent exposure, dose-response, and valuation steps, including location-specific baseline mortality and morbidity risk data to generate location-specific estimates of health benefits. This "bottom-up" approach provides a more accurate representation of regional benefits estimates than a comparable "top-down", emissions-weighted approach might, particularly given the importance of long-range transport for the major pollutants controlled by the Clear Skies Act (SO2 and NOx, as well as mercury).

Recreational visibility benefits can also be geographically disaggregated, based on either the location of the recreational Class I area where visibility is improved, or on the state of origin of visitors to these sites. For this analysis, we disaggregated benefits based on the state of origin of visitors, reflecting the notion that many of the recreational sites with the highest visitation rates are valued by individuals throughout the country, not only by those individuals who live closest to the site. The results of the regional analysis of visibility benefits indicate that benefits are realized throughout the country, with a higher concentration of benefits in those areas of higher population density.

Exhibit 6 provides a list of the health effect endpoints we quantified as part of our analysis of the Clear Skies Act, as well as references to the studies that serve as the basis for the C-R functions. As with emissions and air quality estimates, our estimates of the effect of ambient pollution levels on all of these endpoints represent the best science and analytical tools available. With the exception of the short-term mortality endpoint, the choice of C-R functions and the majority of the analytical assumptions used to develop our estimates have been reviewed and approved by EPA's Science Advisory Board (SAB). The C-R functions in Exhibit 6 only capture effects related to exposures to particulate matter and ozone; they do not include human health effects related to exposures to SO_2, NO_2, or mercury. As a result, for these exposures, we have underestimated the total health benefits attributable to Clear Skies emissions reductions.

Air Quality Changes

As in the analysis of the Heavy-Duty Engine/Diesel Fuel Rule (U.S. EPA, 2000b), the REMSAD PM and CAMx ozone results discussed above served as direct inputs to the CAPMS model. To calculate population exposure to PM, each 8 km by 8 km CAPMS grid cell was assigned to the nearest REMSAD grid cell by calculating the shortest distance between the center of the CAPMS grid cell to the center of a REMSAD grid cell.

To develop baseline and control exposure predictions for ozone, we used the results of the variable-grid Comprehensive Air Quality Model with Extensions (CAMx) for each scenario and observed ozone data for the baseline year (1996). At each ozone monitor, we quantified the relationship between CAMx modeled levels of ozone at the monitor for 1996 and the future year (2010 or 2020). These adjustment ratios are applied to the actual monitoring data to generate estimates of ozone levels at the monitor for the future scenarios. Note that we do not use the modeling data directly to estimate future-year ozone levels. Instead, we use them in a relative sense to simply adjust actual, 1996 ozone monitor levels to future Base Case or Clear Skies levels. This provides a better estimate than the CAMx modeling data itself. To calculate population exposure to ozone, each CAPMS grid cell was assigned a distance-weighted average of adjusted ozone levels from nearby ozone monitors.

Population

Health benefits are related to the change in air pollutant exposure experienced by individuals; because the expected changes in pollutant concentrations vary from location to location, individuals in different parts of the country may not experience the same level of health benefits. We apportioned benefits among individuals by matching the change in air pollutant concentration in each grid cell with the size of the population that experiences that change. We extrapolated grid cell population estimates for future years from 1990 U.S. Census Bureau data according to the method described in U.S. EPA (2000b).

Exhibit 6 Endpoints and Studies Included in the Analysis			
Endpoint	**Pollutant**	**Study**	**Study Population**
Premature Mortality			
Long-term exposure (Base)	$PM_{2.5}$	Krewski, et al. (2000)	Adults, 30 and older
Short-term exposure (Alternative)	$PM_{2.5}$	Schwartz et al. (1996); Schwartz et al. (2000)	< 65 years, ≥ 65 years All Ages
Chronic Illness			
Chronic Bronchitis (pooled estimate)	$PM_{2.5}$ PM_{10}	Abbey, et al. (1995) Schwartz, et al. (1993)	> 26 years > 29 years
Hospitalization			
COPD	PM	Samet, et al. (2000)	> 64 years
Pneumonia	PM	Samet, et al. (2000)	> 64 years
Asthma	PM	Sheppard, et al. (1999)	< 65 years
Total Cardiovascular	PM	Samet, et al. (2000)	> 64 years
All Respiratory Causes	Ozone	Pooled estimate*	All ages
Dysrhythmia	Ozone	Burnett, et al. (1999)	All ages
Asthma-Related ER Visits	PM Ozone	Schwartz, et al. (1993) Pooled estimate*	All ages
Minor Respiratory Illness and Symptoms			
Asthma Attacks	PM and Ozone	Whittemore and Korn (1980)	Asthmatics, all ages
Acute Bronchitis	PM	Dockery et al. (1996)	Children, 8-12 years
Upper Respiratory Symptoms	PM	Pope et al. (1991)	Asthmatic children, 9-11
Lower Respiratory Symptoms	PM	Schwartz et al. (1994)	Children, 7-14 years
Work Loss Days	PM	Ostro (1987)	Adults, 18-65 years
Minor Restricted Activity Days (minus asthma attacks)	PM and Ozone	Ostro and Rothschild (1989)	Adults, 18-65 years

* For a discussion of the procedure for estimating these endpoints see USEPA 2000b.

An epidemiological study typically focuses on a particular age cohort (e.g., adults age 30 and older), and the C-R relationship found in a particular study can not necessarily be generalized across broader age categories. Therefore, to avoid overestimating the benefits of reduced pollution levels, we applied C-R relationships only to those age groups corresponding to the cohorts studied. For outcomes where the study population reflects data limitations and not the age-specificity of a health effect, this assumption may lead us to underestimate the benefits of reductions in pollutant exposures to the entire, exposed population.

Baseline Incidence Rate

Some C-R functions (those expressed as a change relative to baseline conditions) require baseline incidence data associated with ambient levels of pollutants. County mortality rates were used in the estimation of PM-related mortality. For hospital admissions, national level incidence rates were used. In cases where neither county nor national-level incidence rates were available, the baseline incidence from the C-R reference study was applied. Sources for incidence rates are given in U.S. EPA (2000b).

Concentration-Response Functions

We relied on the most recently available, published scientific literature to ascertain the relationship between particulate matter exposure and adverse human health effects. We evaluated studies using the nine selection criteria summarized in Exhibit 7. These criteria include consideration of whether the study was peer-reviewed, the study design and location, and characteristics of the study population, among other considerations. The selection of C-R functions for the benefits analysis is guided by the goal of achieving a balance between comprehensiveness and scientific defensibility. The C-R functions for PM exposure selected for the Base Estimate are the same as those the Environmental Protection Agency used in the Heavy-Duty Engine/Diesel Fuel RIA. The Alternative Estimate uses alternative C-R functions to evaluate the effect of short-term exposure to particulate matter on premature mortality. We present information below on the selection of C-R functions for the two most significant health effects evaluated (in terms of monetized benefits), premature mortality and chronic bronchitis. Detailed information on the selection and application of C-R functions for other endpoints in Exhibit 4 is available in the Heavy-Duty Engine/Diesel Fuel RIA (U.S. EPA, 2000b).

Exhibit 7
Summary of Considerations Used in Selecting C-R Functions

Consideration	Comments
Peer reviewed research	Peer reviewed research is preferred to research that has not undergone the peer review process.
Study type	Among studies that consider chronic exposure (e.g., over a year or longer) prospective cohort studies are preferred over cross-sectional studies (a.k.a. "ecological studies") because they control for important confounding variables that cannot be controlled for in cross-sectional studies. If the chronic effects of a pollutant are considered more important than its acute effects, prospective cohort studies may also be preferable to longitudinal time series studies because the latter type of study is typically designed to detect the effects of short-term (e.g. daily) exposures, rather than chronic exposures. If short-term effects are considered more important, distributed lag approaches, which assume that mortality following a PM event will be distributed over a number of days following the event, are preferred over daily mortality studies. (Daily mortality studies examine the impact of $PM_{2.5}$ on mortality on a single day or over the average of several days).
Study period	Studies examining a relatively longer period of time (and therefore having more data) are preferred, because they have greater statistical power to detect effects. More recent studies are also preferred because of possible changes in pollution mixes, medical care, and life style over time.
Study population	Studies examining a relatively large sample are preferred. Studies of narrow population groups are generally disfavored, although this does not exclude the possibility of studying populations that are potentially more sensitive to pollutants (e.g., asthmatics, children, elderly). However, there are tradeoffs to comprehensiveness of study population. Selecting a C-R function from a study that considered all ages will avoid omitting the benefits associated with any population age category. However, if the age distribution of a study population from an “all population” study is different from the age distribution in the assessment population, and if pollutant effects vary by age, then bias can be introduced into the benefits analysis.
Study location	U.S. studies are more desirable than non-U.S. studies because of potential differences in pollution characteristics, exposure patterns, medical care system, and life style.
Pollutants included in model	Models with more pollutants are generally preferred to models with fewer pollutants, though careful attention must be paid to potential colinearity between pollutants. Because PM has been acknowledged to be an important and pervasive pollutant, models that include some measure of PM are highly preferred to those that do not.
Measure of PM	$PM_{2.5}$ and PM_{10} are preferred to other measures of particulate matter, such as total suspended particulate matter (TSP), coefficient of haze (COH), or black smoke (BS) based on evidence that $PM_{2.5}$ and PM_{10} are more directly correlated with adverse health effects than are these other measures of PM.
Economically valuable health effects	Some health effects, such as forced expiratory volume and other technical measurements of lung function, are difficult to value in monetary terms. These health effects are not quantified in this analysis.
Non-overlapping endpoints	Although the benefits associated with each individual health endpoint may be analyzed separately, care must be exercised in selecting health endpoints to include in the overall benefits analysis because of the possibility of double counting of benefits. Including emergency room visits in a benefits analysis that already considers hospital admissions, for example, will result in double counting of some benefits if the category “hospital admissions” includes emergency room visits.

Concentration-response relationships between a pollutant and a given health endpoint are applied consistently across all locations nationwide. This applies to both C-R relationships defined by a single C-R function and those defined by a pooling of multiple C-R functions. Although the C-R relationship may, in fact, vary from one location to another (for example, due to differences in population susceptibilities or differences in the composition of PM), location-specific C-R functions are generally not available. A single function applied everywhere may result in overestimates of incidence changes in some locations and underestimates elsewhere, but these location-specific biases will negate each other, to some extent, when the total incidence change is calculated. It is not possible to know the extent or direction of the bias in the total incidence change based on the general application of a single C-R function everywhere.

C-R functions may also be estimated with or without explicit thresholds. Air pollution levels below the threshold for each health effect studied are assumed not to cause the effect. When no threshold is assumed, as is often the case in epidemiological studies, any exposure level is assumed to pose a non-zero risk of response to at least one segment of the population. In the benefits analyses for some recent RIAs (e.g., the Regional Haze RIA and the NOx SIP Call RIA), the low-end estimate of benefits assumed a threshold in PM health effects at 15 $\mu g/m^3$. However, the SAB, supported by recent literature addressing this issue (Rossi et al., 1999; Schwartz, 2000), subsequently advised EPA that there is currently no scientific basis for selecting a threshold of 15 $\mu g/m^3$ or any other specific threshold for the PM-related health effects considered in this analysis (EPA-SAB-Council-ADV-99-012, 1999). Therefore, for our benefits analysis, we assume there are no thresholds for modeling health effects. We do, however, present a quantitative sensitivity analysis of this assumption in the results section.

Recently, the Health Effects Institute (HEI) reported findings by investigators at Johns Hopkins University and others that have raised concerns about aspects of the statistical methods used in a number of recent time-series studies of short-term exposures to air pollution and health effects (Greenbaum, 2002a). Some of the concentration-response functions used in this benefits analysis were derived from such short-term studies. The estimates derived from the long-term exposure studies, which account for a major share of the benefits in the Base Estimate, are not affected. As discussed in HEI materials provided to sponsors and to the Clean Air Scientific Advisory Committee (Greenbaum, 2002a, 2002b), these investigators found problems in the default "convergence criteria" used in Generalized Additive Models (GAM) and a separate issue first identified by Canadian investigators about the potential to underestimate standard errors in the same statistical package.[11] These and other investigators have begun to reanalyze the results of several important time series studies with alternative approaches that address these issues and have found a downward revision of some results. For example, the mortality risk estimates for short-term exposure to PM_{10} from NMMAPS were overestimated (this study was *not* used in this benefits analysis of fine particle effects).[12] However, both the relative magnitude and the direction of bias introduced by the convergence issue are case-specific. In most cases, the concentration-response relationship may be overestimated; in other cases, it may be underestimated. The preliminary reanalyses of the mortality and morbidity components of NMMAPS suggest that analyses reporting the lowest relative risks appear to be affected more greatly by this error than studies reporting higher relative risks (Dominici et al., 2002; Schwartz and Zanobetti, 2002).

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[11]Most of the studies used a statistical package known as "S-plus." For further details, see http://www.healtheffects.org/Pubs/NMMAPSletter.pdf.

[12]HEI sponsored the multi-city the National Morbidity, Mortality, and Air Pollution Study (NMMAPS). See http://biosun01.biostat.jhsph.edu/~fdominic/NMMAPS/nmmaps-revised.pdf for revised mortality results.

Our examination of the original studies used in this analysis finds that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions in both the Base and Alternative Estimates; reduced lower respiratory symptoms in the both the Base and Alternative Estimates; and reduced premature mortality due to short-term PM exposures in the Alternative Estimate. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies used in our Clear Skies analyses (Dominici et al, 2002; Schwartz and Zanobetti, 2002; Schwartz, personal communication 2002) suggest a more modest effect of the S-plus error than reported for the NMMAPS PM_{10} mortality study. While we wait for further clarification from the scientific community, we have chosen not to remove these results from the Clear Skies benefits estimates, nor have we elected to apply any interim adjustment factor based on the preliminary reanalyses. EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

Premature Mortality (Particulate Matter)

Both long and short-term exposures to ambient levels of air pollution have been associated with increased risk of premature mortality. The size of the mortality risk estimates from these epidemiological studies, the serious nature of the effect itself, and the high monetary value ascribed to prolonging life make mortality risk reduction the most important health endpoint quantified in this analysis. Because of the importance of this endpoint and the considerable uncertainty among economists and policymakers as to the appropriate way to value reductions in mortality risks, this section discusses some of the issues surrounding the estimation of premature mortality. Additional discussion is found in the section on uncertainties.

Health researchers have consistently linked air pollution, especially PM, with excess mortality. Although a number of uncertainties remain to be addressed by continued research (NRC, 1998), a substantial body of published scientific literature recognizes a correlation between elevated PM concentrations and increased mortality rates. Two types of community epidemiological studies (involving measures of short-term and long-term exposures and response) have been used to estimate PM/ mortality relationships. Short-term studies relate short-term (often day-to-day) changes in PM concentrations and changes in daily mortality rates up to several days after a period of elevated PM concentrations. Long-term studies examine the potential relationship between longer-term (e.g., one or more years) exposure to PM and annual mortality rates. Researchers have found significant associations using both types of studies.

1. Base Estimate

Over a dozen studies have found significant associations between various measures of long-term exposure to PM and elevated rates of annual mortality (e.g. Lave and Seskin, 1977; Ozkaynak and Thurston, 1987). While most of the published studies found positive (but not always significant) associations with available PM indices such as total suspended particles (TSP), fine particles components (i.e. sulfates), and fine particles, exploration of alternative model specifications sometimes found inconsistencies (e.g. Lipfert, 1989). These early "cross-sectional" studies were criticized for a number of methodological limitations, particularly for inadequate control at the individual level for variables that are potentially important in causing mortality, such as wealth, smoking, and diet. More recently, several new, long-term studies have been published that use improved approaches and appear to be consistent with the earlier body of literature. These new "prospective cohort" studies reflect a significant improvement over the earlier work because they include information on individual information with respect to measures related to health status and residence. The most extensive study and analyses has been based on data from two prospective cohort groups, often referred to as the Harvard "Six-City study" (Dockery et al., 1993) and the "American Cancer Society or ACS study" (Pope et al., 1995); these studies have found consistent relationships between fine particle indicators and mortality across multiple locations in the U.S. A third major data set comes from the California based 7th day Adventist study (e.g. Abbey et al, 1999), which reported associations between long-term PM exposure and mortality in men. Results from this cohort, however, have been inconsistent and the air quality results are not geographically representative of most of the US. More recently, a cohort of adult male veterans diagnosed with hypertension has been examined (Lipfert et al., 2000). Unlike previous long-term analyses, this study found some associations between mortality and ozone but found inconsistent results for PM indicators.

Given their consistent results and broad applicability to general US populations, the Six-City and ACS data have been of particular importance in benefits analyses. The credibility of these two studies is further enhanced by the fact that they were subject to extensive reexamination and reanalysis by an independent scientific analysis team of experts compiled by the Health Effects Institute (Krewski et al., 2000). The final results of the reanalysis were then independently peer reviewed by a Special Panel of the HEI Health Review Committee. The results of these reanalyses confirmed and expanded those of the original investigators. This intensive independent reanalysis effort was occasioned both by the importance of the original findings as well as concerns that the underlying individual health effects information has never been made publicly available. The HEI re-examination lends credibility to the original studies but also found unexpected sensitivities concerning (a) which pollutants are most important, (b) the role of education in mediating the association between pollution and mortality, and (c) the magnitude of the association depending on how spatial correlation was handled. Further confirmation and extension of the overall findings using more recent air quality and ACS health information was recently published in the Journal of the American Medical Association (Pope et al., 2002). In general, the risk estimates based on the long-term mortality studies are substantially greater than those derived from short-term studies.

In developing and improving the methods for estimating and valuing the potential reductions in mortality risk over the years, EPA has consulted with a panel of the Science Advisory Board. That panel recommended use of long-term prospective cohort studies in estimating mortality risk reduction (EPA-SAB-COUNCIL-ADV-99-005, 1999). More specifically, the SAB recommended emphasis on Pope, et al. (1995) because it includes a much larger sample size and longer exposure interval, and covers more locations (e.g. 50 cities compared to 6 cities examined in the Harvard data) than other studies of its kind. As explained in the regulatory impact analysis for the Heavy-Duty Engine/Diesel Fuel rule (U.S. EPA, 2000b), more recent EPA benefits analyses have relied on an improved specification from this data set that was developed in the HEI reanalysis of this study (Krewski et al., 2000). The particular specification estimated a C-R function based on changes in mean levels of $PM_{2.5}$, as opposed to the function in the original study, which used median levels. This specification also includes a broader geographic scope than the original study (63 cities versus 50). The SAB has recently agreed with EPA's selection of this specification for use in analyzing mortality benefits of PM reductions (EPA-SAB-COUNCIL-ADV-01-004, 2001). For these reasons, the present analysis uses the same Concentration-Response function in developing the Base Estimate of mortality benefits.

2. Alternative Estimate

To reflect concerns about the inherent limitations in the number of studies supporting a causal association between long-term exposure and mortality, an Alternative benefit estimate was derived from the large number of time-series studies that have established a likely causal relationship between short-term measures of PM and daily mortality statistics. A particular strength of such studies is the fact that potential confounding variables such as socio-economic status, occupation, and smoking do not vary on a day-to-day basis in an individual area. A number of multi-city and other types of studies strongly suggest that these effects-relationships cannot be explained by weather, statistical approaches, or other pollutants. The risk estimates from the vast majority of the short-term studies include the effects of only one or two-day exposure to air pollution. More recently, several studies have found that the practice of examining the effects on a single day basis may significantly understate the risk of short-term exposures (Schwartz, 2000; Zanobetti et al, 2002). These studies suggest that the short-term risk can double when the single-day effects are combined with the cumulative impact of exposures over multiple days to weeks prior to a mortality event.

The fact that the PM-mortality coefficients from the cohort studies are far larger than the coefficients derived from the daily time-series studies provides some evidence for an independent chronic effect of PM pollution on health. Indeed, the Base Estimate presumes that the larger coefficients represent a more complete accounting of mortality effects, including both the cumulative total of short-term mortality as well as an additional chronic effect. This is, however, not the only possible interpretation of the disparity. Various reviewers have argued that 1) the long-term estimates may be biased high and/or 2) the short-term estimates may be biased low. In this view, the two study types could be measuring the same underlying relationship.

Reviewers have noted some possible sources of upward bias in the long-term studies. Some have noted that the less robust estimates based on the Six-Cities Study are significantly higher than those based on the more broadly distributed ACS data sets. Some reviewers have also noted that the observed mortality associations from the 1980's and 90's may reflect higher pollution exposures from the 1950's to 1960's. While this would bias estimates based on more recent pollution levels upwards, it also would imply a truly long-term chronic effect of pollution.

With regard to possible sources of downward bias, it is of note that the recent studies suggest that the single day time series studies may understate the short-term effect on the order of a factor of two. These considerations provide a basis for considering an Alternative Estimate using the most recent estimates from the wealth of time-series studies, in addition to one based on the long-term cohort studies.

In essence, the Alternative Estimate addresses the above noted uncertainties about the relationship between premature mortality and long-term exposures to ambient levels of fine particles by assuming that there is no mortality effect of chronic exposures to fine particles. Instead, it assumes that the full impact of fine particles on premature mortality can be captured using a concentration-response function relating daily mortality to short-term fine particle levels. Specifically, a concentration-response function based on Schwartz et al. (1996) is employed, with an adjustment to account for recent evidence that daily mortality is associated with particle levels from a number of previous days (Schwartz, 2000). Previous daily mortality studies (Schwartz et al., 1996) examined the impact of $PM_{2.5}$ on mortality on a single day or over the average of two or more days. Recent analyses have found that impacts of elevated $PM_{2.5}$ on a given day can elevate mortality on a number of following days (Schwartz, 2000; Samet et al., 2000). Multi-day models are often referred to as "distributed lag" models because they assume that mortality following a PM event will be distributed over a number of days following or "lagging" the PM event.[13]

There are no $PM_{2.5}$ daily mortality studies which report numeric estimates of relative risks from distributed lag models; only PM_{10} studies are available. Daily mortality C-R functions for PM_{10} are consistently lower in magnitude than $PM_{2.5}$-mortality C-R functions, because fine particles are believed to be more closely associated with mortality than the coarse fraction of PM. Given that the emissions reductions under the Clear Skies Act result primarily in reduced ambient concentrations of $PM_{2.5}$, use of a PM_{10} based C-R function results in a significant downward bias in the estimated reductions in mortality. To account for the full potential multi-day mortality impact of acute $PM_{2.5}$ events, we use the distributed lag model for PM_{10} reported in Schwartz (2000) to develop an adjustment factor which we then apply to the $PM_{2.5}$ based C-R function reported in Schwartz et al. (1996).

If most of the increase in mortality is expected to be associated with the fine fraction of PM_{10}, then it is reasonable to assume that the same proportional increase in risk would be observed if a distributed lag model were applied to the $PM_{2.5}$ data. The distributed lag adjustment factor is constructed as the ratio of the estimated coefficient from the unconstrained distributed lag model to the estimated coefficient from the single-lag model reported in Schwartz (2000). The unconstrained distributed lag model coefficient estimate is 0.0012818 and the single-lag model coefficient estimate is 0.0006479. The ratio of these estimates is 1.9784. This adjustment factor is then multiplied by the estimated coefficients from the Schwartz et al. (1996) study. There are two relevant coefficients from the Schwartz et al. (1996) study, one corresponding to all-cause mortality, and one corresponding to chronic obstructive pulmonary disease (COPD) mortality (separation by cause is necessary to implement the life years lost approach detailed below). The adjusted estimates for these two C-R functions are:

$$\text{All cause mortality} = 0.001489 * 1.9784 = 0.002946$$

$$\text{COPD mortality} = 0.003246 * 1.9784 = 0.006422$$

Note that these estimates, while approximating the full impact of daily pollution levels on daily death counts, do not capture any impacts of long-term exposure to air pollution. As discussed earlier, EPA's Science Advisory Board, while acknowledging the uncertainties in estimation of a PM-mortality relationship, has repeatedly recommended the use of a study that

[13] As discussed above, based on recent preliminary findings from the Health Effects Institute, the magnitude of mortality from short-tern exposure (Alternative Estimate) and hospital/ER admissions estimates (both estimates) may be either under or overestimated by an uncertain amount.

does reflect the impacts of long-term exposure. The omission of long-term impacts accounts for approximately 40 percent reduction in the estimate of avoided premature mortality in the Alternative Estimate relative to the Base Estimate.

Chronic Bronchitis

Chronic bronchitis is characterized by mucus in the lungs and a persistent wet cough for at least three months a year for several years in a row. Chronic bronchitis affects an estimated five percent of the U.S. population (American Lung Association, 1999). A limited number of studies have estimated the impact of air pollution on new incidences of chronic bronchitis. Schwartz (1993) and Abbey, et al. (1995) provide evidence that long-term PM exposure leads to the development of chronic bronchitis in the U.S. Following the same approaches of the Heavy-Duty Engine/Diesel Fuel RIA (U.S. EPA, 2000b) and the Section 812 Prospective Report (US EPA, 1999a), this analysis pooled estimates from these two studies to develop a C-R function linking PM to chronic bronchitis. The Schwartz (1993) study examined the relationship between exposure to PM_{10} and prevalence of chronic bronchitis. The Abbey, et al. (1995) study examined the relationship between $PM_{2.5}$ and new incidences of chronic bronchitis. Both studies have strengths and weaknesses, which suggest that pooling the effect estimates from each study, may provide a better estimate of the expected change in incidences of chronic bronchitis than using either study alone.

It should be noted that Schwartz used data on the *prevalence* of chronic bronchitis, not its *incidence*. Following the approach of the Section 812 Prospective Report, we estimated the percentage change in the prevalence rate for chronic bronchitis using the estimated coefficient from Schwartz's study in a C-R function, and then applied this percentage change to a baseline incidence rate obtained from another source. For example, if the prevalence declines by 25 percent with a drop in PM, then baseline incidence drops by 25 percent with the same drop in PM.

Visibility Benefits

As the name chosen for the Clear Skies Act implies, one of the direct consequences of the reductions in fine particles that accompany implementation of the SO_2 and NO_x emissions caps is an improvement in atmospheric clarity and visibility. Changes in the emissions of SO_2 and NO_x caused by the Clear Skies Act will change the level of visibility in much of the U.S by reducing concentrations of sulfate and nitrate particles. Fine particles absorb and scatter light, impairing visibility. Visibility directly affects people's enjoyment of a variety of daily activities both in the places they live and work and in the places they travel to for recreation. The Clean Air Act recognizes visibility as an important public good in naming visibility as one of the aspects of public welfare to be protected in setting secondary NAAQS. In Sections 165 and 169, the Act places particular value on protecting visibility in 156 national parks and wilderness areas (e.g. Shenandoah, Acadia, and Grand Canyon) that are termed class I Federal areas. As noted above, the REMSAD modeling estimates regional and national visibility improvements associated with Clear Skies. As discussed in a subsequent section, this analysis also provides partial estimates of the potential economic value of these visibility improvements.

A number of related measures can be used to measure changes in visibility associated with reduced fine particle concentrations. A key such measure is light "extinction," a measure of the amount of light scattered and absorbed by particles suspended in air. This light scattering and absorption reduces atmospheric clarity and is perceived as haze. Changes in fine particulate mass components are used directly to estimate changes in extinction. Decreasing extinction (in units of inverse distance) can in turn be used to estimate quantitative measures more directly related to human perception such as contrast of distant targets and visual range. More recently, Sisler (1996) created a unitless measure of visibility based directly on the degree of measured light absorption called the *deciview*. Deciviews, like the analagous term decibel, employ a logarithmic scale to evaluate relative changes in visibility that is more directly related to human perception. Sisler characterized a change in light extinction of one deciview as "a small but perceptible scenic change under many circumstances." For this analysis, REMSAD version 6.40 was used to predict the change in visibility, measured in deciviews and presented graphically, of the areas affected by the Clear Skies Act.

Economic Valuation of Benefits

The overall approach applied in our estimates of the benefits of the Clear Skies Act closely parallels that used in prior EPA analyses, including the Section 812 series of Reports to Congress (U.S. EPA, 1996 and 1999) and the recent Heavy-Duty Engine/Diesel Fuel RIA (U.S. EPA, 2000b). As in those analyses, the EPA has not conducted extensive new primary research to measure economic benefits for individual rulemakings. As a result, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary benefits research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Where appropriate, we have made adjustments to existing primary research for the level of environmental quality change, the sociodemographic and economic characteristics of the affected population, and other factors in order to improve the accuracy and robustness of benefits estimates.

In general, economists tend to view an individual's willingness-to-pay (WTP) for an improvement in environmental quality as the most complete and appropriate measure of the value of an environmental or health risk reduction. An individual's willingness-to-accept (WTA) compensation for not receiving the improvement is also a valid measure. Willingness to pay and Willingness to accept are comparable measures when the change in environmental quality is small and there are reasonably close substitutes available. However, WTP is generally considered to be a more readily measurable and conservative measure of benefits. Adoption of WTP as the measure of value implies that the value of environmental quality improvements is dependent on the individual preferences of the affected population and that the existing distribution of income (ability to pay) is appropriate.

Our analysis relies on up-to-date reviews of the relevant resource economics literature that provides WTP values for health risk reductions and visibility improvements similar to those that will be provided by implementation of the Clear Skies Act. Exhibit 8 provides a summary of the base WTP values used to generate estimates of the economic value of avoided health effects for this analysis, adjusted to 1999 dollars, and a brief description of the basis for these values. Exhibit 9 provides a summary of the monetary values for the Alternative Estimate used for economic valuation of mortality and chronic bronchitis. For these two endpoints, the Alternative Estimate valuation differs from the Base Estimate values.

In the sections that follow, we discuss in greater detail the basis for generating WTP for premature mortality risk reductions and WTP for reductions in the risk of contracting chronic bronchitis and the basis for making adjustments to unit values to make them more applicable to the air pollution reductions we anticipate from the Clear Skies Act. The mortality and chronic bronchitis health endpoints are the most influential in our estimation of monetized benefits, because they account for over 95 percent of the total estimated monetized benefits of the Clear Skies Act. In addition, we provide a brief summary of our approach to valuing visibility and agricultural yield improvements. Detailed descriptions of the basis for other economic valuation methods can be found in Chapter VII of EPA’s Heavy-Duty Engine/Diesel Fuel RIA (U.S. EPA, 2000b).

Exhibit 8 Unit Values Used for Economic Valuation of Health Endpoints		
Health or Welfare Endpoint	**Estimated Value Per Incidence (1999$) Base Estimate**	**Derivation of Estimates**
Premature Mortality		
Long-term Exposure (Base)	$6,120,000 per case[1]	Value is the mean of value-of-statistical-life estimates from 26 studies (5 contingent valuation and 21 labor market studies) reviewed for the Section 812 Costs and Benefits of the Clean Air Act, 1990-2010 (US EPA, 1999).
Short-term Exposure (Alternative)	Varies by age and years life lost	See section on Valuation of Premature Mortality, Alternative Estimate, in text
Chronic Bronchitis (CB)		
Chronic Bronchitis (Base)	$331,000 per case[2]	Value is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB.
Chronic Bronchitis (Alternative)	$107,000 per case	Cost of Illness (COI) estimate is based on Cropper and Krupnick (1990).
Hospital Admissions		
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	Cost of Illness (COI) estimates are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Elixhauser (1993).
Pneumonia (ICD codes 480-487)	$14,693	
Asthma admissions	$6,633	
All Cardiovascular (ICD codes 390-429)	$18,387	
All Respiratory	Variable	
Dysrhythmia	$12,441	
Emergency room visits for asthma	$299	COI estimate based on data reported by Smith, et al. (1997).
Respiratory Ailments Not Requiring Hospitalization		
Upper Respiratory Symptoms (URS)	$24 per case[3]	Combinations of the 3 symptoms for which WTP estimates are available that closely match those listed by Pope, et al. result in 7 different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming WTPs are additive. The dollar value for URS is the average of the dollar values for the 7 different types of URS.
Lower Respiratory Symptoms (LRS)	$15 per case[3]	Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz, et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming WTPs are additive. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Acute Bronchitis	$57 per case[3]	Average of low and high values recommended for use in Section 812 analysis (Neumann, et al. 1994)

Exhibit 8 Unit Values Used for Economic Valuation of Health Endpoints		
Health or Welfare Endpoint	**Estimated Value Per Incidence (1999$) Base Estimate**	**Derivation of Estimates**
Restricted Activity and Work Loss Days		
Work Loss Days (WLDs)	$105.83 per case[4]	Regionally adjusted median weekly wage for 1990 divided by 5 (adjusted to 1999$) (US Bureau of the Census, 1992).
Minor Restricted Activity Days (MRADs)	$48 per case[3]	Median WTP estimate to avoid one MRAD from Tolley, et al. (1986).

[1] This value does not reflect the 5-year lag adjustment and the adjustment for changes in real income over time that are included in the mortality valuation in our national benefits summaries. The lag adjustment distributes the mortality incidence over five years (25 percent in each of the first two years, and 17 percent for each of the remaining years) and discounts mortality benefits over this period at a rate of three percent. The adjustment to the mortality unit valuation for growth in real income in 2020 is achieved using an adjustment factor of 1.278.
[2] This value does not reflect the adjustment for changes in real income over time that is included in the chronic bronchitis valuation in our national benefits summaries. The adjustment to the chronic bronchitis unit valuation for growth in real income in 2020 is achieved using an adjustment factor of 1.319.
[3] These values do not reflect the adjustment for changes in real income over time that is included in the benefit valuations in our national benefits summaries. The adjustment to the unit valuations of these endpoints for growth in real income in 2020 is achieved using an adjustment factor of 1.089.
[4] The value of a Work Loss Day presented here represents the national median. The valuation of Work Loss Days presented in our national benefits summaries, however, incorporates county-specific adjustment factors to account for variations in regional income.

Valuation of Premature Mortality

1. <u>Base Estimate</u>

The monetary benefit of reducing premature mortality risk was estimated using the "value of statistical lives saved" (VSL) approach, although the actual valuation is of small changes in mortality risk experienced by a large number of people. The VSL approach applies information from several published value-of-life studies, which themselves examine tradeoffs of monetary compensation for small additional mortality risks, to determine a reasonable benefit of preventing premature mortality. The mean value of avoiding one statistical death (i.e., the statistical incidence of a single death, equivalent to a product of a population risk times a population size that equals one) is estimated to be $6 million in 1999 dollars. This represents an intermediate value from a range of estimates that appear in the economics literature, and it is a value the EPA uses in rulemaking support analyses and in the Section 812 Reports to Congress.

This estimate is the mean of a distribution fitted to the estimates from 26 value-of-life studies identified in the Section 812 reports as "applicable to policy analysis." The approach and set of selected studies mirrors that of Viscusi (1992) (with the addition of two studies), and uses the same criteria as Viscusi in his review of value-of-life studies. The $6 million estimate is consistent with Viscusi's conclusion (updated to 1999$) that "most of the reasonable estimates of the value of life are clustered in the $3.7 to $8.6 million range." 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, controlling for other job and employee characteristics such as education and experience. As indicated in the previous section on quantification of premature mortality benefits, we assume for this analysis that some of the incidences of premature mortality related to PM exposures occur in a distributed fashion over the five years following exposure. To take this into account in the valuation of reductions in premature mortality, we apply an annual three percent discount rate to the value of premature mortality occurring in future years.[14]

The economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. The adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economic and public policy analysis community. Regardless of the theoretical economic considerations, distinctions in the monetary value assigned to the lives saved were not drawn, even if populations differed in age, health status, socioeconomic status, gender or other characteristics.

Following the advice of the EEAC of the SAB, the VSL approach was used to calculate the Base Estimate of mortality benefits (EPA-SAB-EEAC-00-013). While there are several differences between the risk context implicit in labor market studies we use to derive a VSL estimate and the particulate matter air pollution context addressed here, those differences in the affected populations and the nature of the risks imply both upward and downward adjustments. For example, adjusting for age differences between subjects in the economic studies and those affected by air pollution may imply the need to adjust the $6 million VSL downward, but the involuntary nature of air pollution-related risks and the lower level of risk-aversion of the manual laborers in the labor market studies may imply the need for upward adjustments. In certain cases, labor market studies have not adequately controlled for non-fatal injury risks and other unfavorable job attributes (e.g. dirt and noise). These factors may increase the estimated risk premium for reductions in premature mortality risk.

Some economists emphasize that the value of a statistical life is not a single number relevant for all situations. Indeed, the VSL estimate of $6 million (1999 dollars) is itself the central tendency of a number of estimates of the VSL for some rather narrowly defined populations. When there are significant differences between the population affected by a particular health risk and the populations used in the labor market studies, as is the case here, some economists prefer to adjust the VSL estimate to reflect those differences. The CV-based estimates of VSL collectively may better represent the population affected by pollution than the labor market studies.

There is general agreement that the value to an individual of a reduction in mortality risk can vary based on several factors, including the age of the individual, the type of risk, the level of control the individual has over the risk, the individual's attitudes towards risk, and the health status of the individual. While the empirical basis for adjusting the $6 million VSL for many of these factors does not yet exist, a thorough discussion of these uncertainties is included in EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000a). The EPA recognizes the need for investigation by the scientific community to develop additional empirical support for adjustments to VSL for the factors mentioned above.

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[14] The choice of a discount rate, and its associated conceptual basis, is a topic of ongoing discussion within the federal government. We adopted a 3 percent discount rate for our Base analysis in this case to reflect reliance on a "social rate of time preference" discounting concept. We have also calculated benefits using a 7 percent rate consistent with an "opportunity cost of capital" concept to reflect the time value of resources directed to meet regulatory requirements. In this analysis, the benefit estimates were not significantly affected by the choice of discount rate. Further discussion of this topic appears in EPA's *Guidelines for Preparing Economic Analyses*, EPA 240-R-00-003, September 2000.

As further support for the Base Estimate, the SAB-EEAC advised in their recent report that the EPA "continue to use a wage-risk-based VSL as its Base Estimate, including appropriate sensitivity analyses to reflect the uncertainty of these estimates," and that "the only risk characteristic for which adjustments to the VSL can be made is the timing of the risk"(EPA-SAB-EEAC-00-013). In developing the Base Estimate of the benefits of premature mortality reductions, we have discounted over the lag period between exposure and premature mortality. However, in accordance with the SAB advice, we use the VSL in the Base Estimate and present age adjusted values in the tables of alternative calculations, Exhibit 12 and 13.

2. Alternative Estimate

The Alternative Estimate reflects the impact of changes to key assumptions associated with the valuation of mortality. These include: 1) the impact of using wage-risk and contingent valuation-based value of statistical life estimates in valuing risk reductions from air pollution as opposed to contingent valuation-based estimates alone, 2) the relationship between age and willingness-to-pay for fatal risk reductions, and 3) the degree of prematurity in mortalities from air pollution.

The Alternative Estimate addresses this issue by using an estimate of the value of statistical life that is based only on the set of five contingent valuation studies included in the larger set of 26 studies recommended by Viscusi (1992) as applicable to policy analysis. The mean of the five contingent valuation based VSL estimates is $3.7 million (1999$), which is approximately 60 percent of the mean value of the full set of 26 studies.

The second issue is addressed by assuming that the relationship between age and willingness-to-pay for fatal risk reductions can be approximated using an adjustment factor derived from Jones-Lee (1989). The SAB has advised the EPA that the appropriate way to account for age differences is to obtain the values for risk reductions from the age groups affected by the risk reduction. Several studies have found a significant effect of age on the value of mortality risk reductions expressed by citizens in the United Kingdom (Jones-Lee et al., 1985; Jones-Lee, 1989; Jones-Lee, 1993).

Two of these studies provide the basis to form ratios of the WTP of different age cohorts to a base age cohort of 40 years. These ratios can be used to provide Alternative age-adjusted estimates of the value of avoided premature mortalities. One problem with both of the Jones-Lee studies is that they examine VSL for a limited age range. They then fit VSL as a function of age and extrapolate outside the range of the data to obtain ratios for the very old. Unfortunately, because VSL is specified as quadratic in age, extrapolation beyond the range of the data can lead to a very severe decline in VSL at ages beyond 75.

A simpler and potentially less biased approach is to simply apply a single age adjustment based on whether the individual was over or under 65 years of age at the time of death. This is consistent with the range of observed ages in the Jones-Lee studies and also agrees with the findings of more recent studies by Krupnick et al. (2000) that the only significant difference in WTP is between the over 70 and under 70 age groups. To correct for the potential extrapolation error for ages beyond 70, the adjustment factor is selected as the ratio of a 70 year old individual's WTP to a 40 year old individual's WTP, which is 0.63, based on the Jones-Lee

(1989) results and 0.92 based on the Jones-Lee (1993) results. To show the maximum impact of the age adjustment, the Alternative Estimate is based on the Jones-Lee (1989) adjustment factor of 0.63, which yields a VSL of $2.3 million for populations over the age of 70. Deaths of individuals under the age of 70 are valued using the unadjusted mean VSL value of $3.7 million (1999$). Since these are acute mortalities, it is assumed that there is no lag between reduced exposure and reduced risk of mortality.

Jones-Lee and Krupnick may understate the effect of age because they only control for income and do not control for wealth. While there is no empirical evidence to support or reject hypotheses regarding wealth and observed WTP, WTP for additional life years by the elderly may in part reflect their wealth position vis a vis middle age respondents.

The third issue is addressed by assuming that deaths from chronic obstructive pulmonary disease (COPD) are advanced by 6 months, and deaths from all other causes are advanced by 5 years. These reductions in life years lost are applied regardless of the age at death. Actuarial evidence suggests that individuals with serious preexisting cardiovascular conditions have a remaining life expectancy of around 5 years. While many deaths from daily exposure to PM may occur in individuals with cardiovascular disease, studies have shown relationships between all cause mortality and PM, and between PM and mortality from pneumonia (Schwartz, 2000). In addition, recent studies have shown a relationship between PM and non-fatal heart attacks, which suggests that some of the deaths due to PM may be due to fatal heart attacks (Peters et al., 2001). And, a recent meta-analysis has shown little effect of age on the relative risk from PM exposure (Stieb et al. 2002), which suggests that the number of deaths in non-elderly populations (and thus the potential for greater loss of life years) may be significant. Indeed, this analysis estimates that 21 percent of non-COPD premature deaths avoided are in populations under 65. Thus, while the assumption of 5 years of life lost may be appropriate for a subset of total avoided premature mortalities, it may over or underestimate the degree of life shortening attributable to PM for the remaining deaths."

In order to value the expected life years lost for COPD and non-COPD deaths, we need to construct estimates of the value of a statistical life year. The value of a life year varies based on the age at death, due to the differences in the base VSL between the 65 and older population and the under 65 population. The valuation approach used is a value of statistical life years (VSLY) approach, based on amortizing the base VSL for each age cohort. Previous applications have arrived at a single value per life year based on the discounted stream of values that correspond to the VSL for a 40 year old worker (U.S. EPA, 1999a). This assumes 35 years of life lost is the base value associated with the mean VSL value of $3.7 million (1999$). The VSLY associated with the $3.7 million VSL is $163,000, annualized assuming EPA’s guideline value of a 3 percent discount rate, or $270,000, annualized assuming OMB’s guideline value of a 7 percent discount rate. The VSL applied in this analysis is then built up from that VSLY by taking the present value of the stream of life years, again assuming a 3% discount rate. Thus, if you assume that a 40 year-old dying from pneumonia would lose 5 years of life, the VSL applied to that death would be $0.79 million. For populations over age 65, we then develop a VSLY from the age-adjusted base VSL of $2.3 million. Given an assumed remaining life expectancy of 10 years, this gives a VSLY of $258,000, assuming a 3 percent discount rate. Again, the VSL is built based on the present value of 5 years of lost life, so in this case, we have a 70 year old individual dying from pneumonia losing 5 years of life, implying an estimated VSL of $1.25 million. As a final step, these estimated VSL values are multiplied by the appropriate adjustment factors to account for changes in WTP over time, as outlined above.

Applying the VSLY approach to the four categories of acute mortality results in four separate sets of values for an avoided premature mortality based on age and cause of death. Non-COPD deaths for populations aged 65 and older are valued at $1.4 million per incidence in 2010, and $1.6 million in 2020. Non-COPD deaths for populations aged 64 and younger are valued at $0.88 million per incidence in 2010, and $1.0 million in 2020. COPD deaths for populations aged 65 and older are valued at $0.15 million per incidence in 2010, and $0.17 million in 2020. Finally, COPD deaths for populations aged 64 and younger are valued at $0.096 million per incidence in 2010, and $0.11 million in 2020. The implied VSL for younger populations is less than that for older populations because the value per life year is higher for older populations. Since we assume that there is a 5-year loss in life years for a PM related mortality, regardless of the age of person dying, this necessarily leads to a lower VSL for younger populations.

Valuation of Avoided Cases of Chronic Bronchitis

1. Base Estimate

The best available estimate of WTP to avoid a case of chronic bronchitis (CB) comes from Viscusi, et al. (1991). The Viscusi, et al. study, however, describes a severe case of CB to the survey respondents. We therefore employ an estimate of WTP to avoid a pollution-related case of CB, based on adjusting the Viscusi, et al. (1991) estimate of the WTP to avoid a severe case. This is done to account for the likelihood that an average case of pollution-related CB is not as severe. The adjustment is made by applying the elasticity of WTP with respect to severity reported in the Krupnick and Cropper (1992) study. Details of this adjustment procedure can be found in the Heavy-Duty Engine/Diesel Fuel RIA and its supporting documentation, and in the most recent Section 812 study (EPA 1999).

We use the mean of a distribution of WTP estimates as the central tendency estimate of WTP to avoid a pollution-related case of CB in this analysis. The distribution incorporates uncertainty from three sources: (1) the WTP to avoid a case of severe CB, as described by Viscusi, et al.; (2) the severity level of an average pollution-related case of CB (relative to that of the case described by Viscusi, et al.); and (3) the elasticity of WTP with respect to severity of the illness. Based on assumptions about the distributions of each of these three uncertain components, we derive a distribution of WTP to avoid a pollution-related case of CB by statistical uncertainty analysis techniques. The expected value (i.e., mean) of this distribution, which is about $331,000 (1999$), is taken as the central tendency estimate of WTP to avoid a PM-related case of CB.

2. Alternative Estimate

For the Alternative Estimate, a cost-of illness value is used in place of willingness-to-pay to reflect uncertainty about the value of reductions in incidences of chronic bronchitis. In the Base Estimate, the willingness-to-pay estimate was derived from two contingent valuation studies (Viscusi et al., 1991; Krupnick and Cropper, 1992). These studies were experimental studies intended to examine new methodologies for eliciting values for morbidity endpoints. Although these studies were not specifically designed for policy analysis, the SAB (EPA-SAB-COUNCIL-ADV-00-002, 1999) has indicated that the severity-adjusted values from this study provide reasonable estimates of the WTP for avoidance of chronic bronchitis. As with other contingent valuation studies, the reliability of the WTP estimates depends on the methods used to obtain the WTP values. In order to investigate the impact of using the CV based WTP estimates, the Alternative Estimate relies on a value for incidence of chronic bronchitis using a cost-of-illness estimate based Cropper and Krupnick (1990) which calculates the present value of the lifetime expected costs associated with the illness. The current cost-of-illness (COI) estimate for chronic bronchitis is around $107,000 per case, compared with the current WTP estimate of $330,000.

Valuation of Changes in Visibility

Estimating benefits for visibility is a more difficult and less precise exercise than estimating health benefits because the endpoints are not directly or indirectly valued in markets. The contingent valuation (CV) method has been employed in the economics literature to value endpoint changes for visibility (Chestnut and Rowe, 1990a, 1990b; Chestnut and Dennis, 1997). The CV method values endpoints by using carefully structured surveys to ask a sample of people what amount of compensation is equivalent to a given change in environmental quality. There is an extensive scientific literature and body of practice on both the theory and technique of CV. The EPA believes that well-designed and well-executed CV studies are valid for estimating the benefits of air quality regulation.[15]

Individuals value visibility both in the places they live and work (referred to as residential visibility), and in the places they travel to for recreational purposes (referred to as recreational visibility). Although CV studies that address both types of visibility exist, in our analysis we rely only on recreational visibility studies, as explained further below.

We considered benefits from two categories of visibility changes: residential visibility and recreational visibility. Residential visibility benefits are those that occur from visibility changes in urban, suburban, and rural areas, and also in recreational areas **not** listed as federal Class I areas.[16] For the purposes of this analysis, recreational visibility improvements are defined as those that occur specifically in federal Class I areas. A key distinction between recreational and residential benefits is that only those people living in residential areas are assumed to receive benefits from residential visibility, while all households in the U.S. are assumed to derive some benefit from improvements in Class I areas.

Only two existing studies provide defensible monetary estimates of the value of visibility

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[15]Concerns about the reliability of value estimates from CV studies arose because research has shown that bias can be introduced easily into these studies if they are not carefully conducted. Accurately measuring WTP for avoided health and welfare losses depends on the reliability and validity of the data collected. There are several issues to consider when evaluating study quality, including but not limited to 1) whether the sample estimates of WTP are representative of the population WTP; 2) whether the good to be valued is comprehended and accepted by the respondent; 3) whether the WTP elicitation format is designed to minimize strategic responses; 4) whether WTP is sensitive to respondent familiarity with the good, to the size of the change in the good, and to income; 5) whether the estimates of WTP are broadly consistent with other estimates of WTP for similar goods; and 6) the extent to which WTP responses are consistent with established economic principles.

[16] The Clean Air Act designates 156 national parks and wilderness areas as Class I areas for visibility protection.

changes. One is a study on residential visibility conducted in 1990 (McClelland, et. al., 1993) and the other is a 1988 survey on recreational visibility value (Chestnut and Rowe, 1990a; 1990b). Both utilize the contingent valuation method. There has been a great deal of controversy and significant development of both theoretical and empirical knowledge about how to conduct CV surveys in the past decade. In EPA's judgment, the Chestnut and Rowe study contains many of the elements of a valid CV study and is sufficiently reliable to serve as the basis for monetary estimates of the benefits of visibility changes in recreational areas.[17] This study serves as an essential input to our estimates of the benefits of recreational visibility improvements. Consistent with SAB advice, the EPA has designated the McClelland, et al. study as significantly less reliable for regulatory benefit-cost analysis, although it does provide useful estimates on the order of magnitude of residential visibility benefits (EPA-SAB-COUNCIL-ADV-00-002, 1999). Residential visibility benefits are therefore only included as part of our sensitivity tests. The methods for this calculation are similar to the procedure for recreational benefits.

The Chestnut and Rowe study measured the demand for visibility in Class I areas managed by the National Park Service (NPS) in three broad regions of the country: California, the Southwest, and the Southeast. Respondents in five states were asked about their willingness to pay to protect national parks or NPS-managed wilderness areas within a particular region. The survey used photographs reflecting different visibility levels in the specified recreational areas. The visibility levels in these photographs were later converted to deciviews for the current analysis. The survey data collected were used to estimate a WTP equation for improved visibility. In addition to the visibility change variable, the estimating equation also included household income as an explanatory variable.

The Chestnut and Rowe study did not measure values for visibility improvement in Class I areas outside the three regions. Their study covered 86 of the 156 Class I areas in the U.S. We can infer the value of visibility changes in the other Class I areas by transferring values of visibility changes at Class I areas in the study regions. However, these values are not as defensible and are thus presented only as a sensitivity calculation.

The estimated relationship from the Chestnut and Rowe study is only directly applicable to the populations represented by survey respondents. We used benefits transfer methods to extrapolate these results to the population affected by the Clear Skies Act. A general willingness

[17] An SAB advisory letter indicates that "many members of the Council believe that the Chestnut and Rowe study is the best available." (EPA-SAB-COUNCIL-ADV-00-002, 1999) However, the committee did not formally approve use of these estimates because of concerns about the peer-reviewed status of the study. EPA believes the study has received adequate review and has been cited in numerous peer-reviewed publications (Chestnut and Dennis, 1997).

to pay equation for improved visibility (measured in deciviews) was developed as a function of the baseline level of visibility, the magnitude of the visibility improvement, and household income. The behavioral parameters of this equation were taken from analysis of the Chestnut and Rowe data. These parameters were used to calibrate WTP for the visibility changes resulting from the Clear Skies Act. The method for developing calibrated WTP functions is based on the approach developed by Smith, et al. (1999). Available evidence indicates that households are willing to pay more for a given visibility improvement as their income increases (Chestnut, 1997). The benefits estimates here incorporate Chestnut's estimate that a one percent increase in income is associated with a 0.9 percent increase in WTP for a given change in visibility.

For the sensitivity test calculation for residential visibility, the McClelland, et al. study's results were used to calculate the parameter to measure the effect of deciview changes on WTP. The WTP equation was then run for the population affected by the Clear Skies Act.

Agricultural Benefits

The Ozone Criteria Document notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant" (US EPA, 1996). Reduced levels of ground-level ozone resulting from the final Clear Skies Act will have generally beneficial results on agricultural crop yields and commercial forest growth. Well-developed techniques exist to provide monetary estimates of these benefits to agricultural producers and consumers. These techniques use models of planting decisions, yield response functions, and agricultural product supply and demand. The resulting welfare measures are based on predicted changes in market prices and production costs.

Laboratory and field experiments have shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN), examined 15 species and numerous cultivars. The NCLAN results show that "several economically important crop species are sensitive to ozone levels typical of those found in the U.S." (US EPA, 1996). In addition, economic studies have shown a relationship between observed ozone levels and crop yields (Garcia, et al., 1986).

To estimate changes in crop yields, we used biological exposure-response information derived from controlled experiments conducted by the NCLAN (NCLAN, 1996). For the purpose of our analysis, we analyze changes for the six most economically significant crops for which C-R functions are available: corn, cotton, peanuts, sorghum, soybean, and winter wheat.[18] For some crops there are multiple C-R functions, some more sensitive to ozone and some less. Our estimate assumes that crops are evenly mixed between relatively sensitive and relatively insensitive varieties.

We analyzed the economic value associated with varying levels of yield loss for ozone-sensitive commodity crops using the AGSIM© agricultural benefits model (Taylor, et al., 1993). AGSIM© is an econometric-simulation model that is based on a large set of statistically

[18] The total value for these crops in 1998 was $47 billion.

estimated demand and supply equations for agricultural commodities produced in the United States. The model is capable of analyzing the effects of changes in policies that affect commodity crop yields or production costs.[19]

The measure of benefits calculated by the model is the net change in consumer and producer surplus from baseline ozone concentrations to the ozone concentrations resulting from attainment of particular standards. Using the baseline and post-control equilibria, the model calculates the change in net consumer and producer surplus on a crop-by-crop basis.[20] Dollar values are aggregated across crops for each standard. The total dollar value represents a measure of the change in social welfare associated with implementation of the Clear Skies Act.

Adjustments for Changes in Income Over Time

Recent SAB deliberations on mortality and morbidity valuation approaches suggest that some adjustments to unit values are appropriate to reflect economic theory (EPA-SAB-EEAC-00-013, 2000). As noted above, we apply one adjustment by discounting lagged mortality incidence effects. A second adjustment is conducted as part of the mortality, morbidity, and visibility valuation procedures to incorporate the effect of changes in income over time on WTP. To estimate the effects of changes in income over time we use a procedure originally outlined in Appendix H of the Section 812 Prospective Report to Congress (EPA 1999). That procedure uses per capita income estimates generated from Federal Government projections of income and population growth, and applies three different income elasticities for mortality, severe morbidity, and light symptom effects.[21]

Benefits for each of the categories - minor health effects, severe and chronic health effects (which include chronic bronchitis and premature mortality), and visibility - were adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor, listed in Exhibit 10 below.

[19] AGSIM© is designed to forecast agricultural supply and demand out to 2010. We were not able to adapt the model to forecast out to 2020. Instead, we apply percentage increases in yields from decreased ambient ozone levels in 2020 to 2010 yield levels, and input these into an agricultural sector model held at 2010 levels of demand and supply. It is uncertain what impact this assumption will have on net changes in surplus.

[20] Agricultural benefits differ from other health and welfare endpoints in the length of the assumed ozone season. For agriculture, the ozone season is assumed to extend from April to September. This assumption is made to ensure proper calculation of the ozone statistic used in the exposure-response functions. The only crop affected by changes in ozone during April is winter wheat.

[21] Note that the Environmental Economics Advisory Committee (EEAC) of the SAB advised EPA to adjust WTP for increases in real income over time, but not to adjust WTP to account for cross-sectional income differences "because of the sensitivity of making such distinctions, and because of insufficient evidence available at present" (EPA-SAB-EEAC-00-013).

Exhibit 10 Adjustment Factors Used to Account for Projected Real Income Growth through 2010 and 2020		
Benefit Category	**Adjustment Factor (2010)**	**Adjustment Factor (2020)**
Minor Health Effect	1.038	1.089
Severe and Chronic Health Effects	1.127	1.319
Premature Mortality	1.112	1.278
Visibility	1.272	1.758

The procedure used to develop these adjustment factors is described in more detail in the Heavy-Duty Engine/Diesel Fuel RIA (U.S. EPA, 2000b). Also note that no adjustments were made to benefits based on the cost-of-illness approach or to work loss days. This assumption will also lead us to underpredict benefits since it is likely that increases in real U.S. income would also result in increased cost-of-illness (due, for example, to increases in wages paid to medical workers) and increased cost of work loss days (reflecting that if worker incomes are higher, the losses resulting from reduced worker production would also be higher). The result of applying these adjustment factors is an updated set of unit economic values used in the valuation step. We summarize these adjusted values in Exhibit 11.

Exhibit 11
Effective Unit Health Effects Valuation for The Clear Skies Act (1999 dollars), Incorporating Adjustments for Income Growth and Mortality Lag

Endpoint	Pollutant	Valuation per case (2010 mean est.)	Valuation per case (2020 mean est.)
Mortality			
Mortality, chronic exposure	$PM_{2.5}$	$6,470,000	$7,440,000 [1]
Short-Term Exposure, Non-COPD Related, > 65	$PM_{2.5}$	$1,400,000	$1,600,000 [1]
Short-Term Exposure, Non-COPD Related, ≤ 64	$PM_{2.5}$	$880,000	$1,000,000 [1]
Short-Term Exposure, COPD Related, > 65	$PM_{2.5}$	$150,000	$170,000 [1]
Short-Term Exposure, COPD Related, ≤ 64	$PM_{2.5}$	$96,000	$110,000 [1]
Chronic Illness			
Chronic Bronchitis (WTP, Base Estimate)	PM_{10}, $PM_{2.5}$	$385,000	$437,000 [2]
Chronic Bronchitis (COI, Alternative Estimate)	PM_{10},$PM_{2.5}$	$107,000	$107,000
Hospitalization			
COPD Admissions	PM_{10}	$12,400	$12,400
Pneumonia Admissions	PM_{10}	$14,700	$14,700
Cardiovascular Admissions	PM_{10}	$18,400	$18,400
Asthma Admissions	$PM_{2.5}$	$6,600	$6,600
All Respiratory	Ozone	$14,100	$14,100
Dysrhythmia	Ozone	$12,400	$12,400
Emergency Room Visits for Asthma	PM_{10} and Ozone	$300	$300
Minor Respiratory Illness and Symptoms			
Acute Bronchitis	$PM_{2.5}$	$60	$62 [3]
Upper Respiratory Symptoms	PM_{10}	$25	$26 [3]
Lower Respiratory Symptoms	$PM_{2.5}$	$16	$17 [3]
Work Loss Days	PM_{10}	$106	$106 [4]
Minor Restricted Activity Days	PM_{10} and Ozone	$50	$53 [3]

[1] This value reflects *both* the 5-year lag adjustment and the adjustments for changes in real income over time that are included in the mortality valuation in our national benefits summaries. The lag adjustment distributes the mortality incidence over five years (25 percent in each of the first two years, and 17 percent for each of the remaining years) and discounts mortality benefits over this period at a rate of three percent. The adjustment to the mortality unit valuation for growth in real income in 2010 is achieved using an adjustment factor of 1.112. For 2020, the adjustment factor is 1.278.
[2] This value reflects the adjustment for changes in real income over time that is included in the chronic bronchitis valuation in our national benefits summaries. The adjustment to the chronic bronchitis unit valuation for growth in real income in 2010 is achieved using an adjustment factor of 1.127. For 2020, the adjustment factor is 1.319.
[3] These values reflect the adjustment for changes in real income over time that is included in the benefit valuations in our national benefits summaries. The adjustment to the unit valuations of these endpoints for growth in real income in 2010 is achieved using an adjustment factor of 1.038. For 2020, the adjustment factor is 1.089.
[4] The value of a Work Loss Day presented here represents the national median. The valuation of Work Loss Days presented in our national benefits summaries, however, incorporates county-specific adjustment factors to account for variations in regional income.

Totals may not sum due to rounding.

III. MAJOR UNCERTAINTIES IN BENEFITS ANALYSIS

The estimates of avoided health effects, improved visibility, and monetary benefits of the Clear Skies Act are based on a method that reflects peer-reviewed data, models, and approaches that are applied to support EPA rulemakings and generate Reports to Congress on the benefits of air pollution regulation. Although EPA has made a concerted effort to apply well-accepted methods, there remain significant uncertainties in the estimation of these benefits. There are three types of uncertainty that affect these estimates:

- ***Quantifiable uncertainty in benefits estimates.*** In other analyses, EPA has developed quantitative characterizations of the uncertainty and variability in the estimates developed here. Quantitative uncertainty may include measurement uncertainty or variation in estimates across or within studies. For example, the variation in VSL results across the 26 studies that underlie the Base Estimate represent a quantifiable uncertainty.

- ***Uncertainty in the basis for quantified estimates.*** Often it is possible to identify a source of uncertainty (for example, an ongoing debate over the proper method to estimate premature mortality) that is not readily addressed through traditional uncertainty analysis. In these cases, it is possible to characterize the potential impact of this uncertainty on the overall benefits estimates through sensitivity analyses.

- ***Nonquantifiable uncertainty.*** Uncertainties may also result from omissions of known effects from the benefits calculation, perhaps owing to a lack of data or modeling capability. For example, in this analysis we were unable to quantify the benefits of avoided airborne nitrogen deposition on aquatic and terrestrial ecosystems, or avoided health and environmental effects associated with reductions in atmospheric mercury emissions.

In the remainder of this section, we discuss the major sources of each of these three categories of uncertainty related to the estimate of avoided health effects, avoided ecological effects, and monetary valuation of these benefits. Our analysis of the Clear Skies Act has not included formal uncertainty analyses, although we have conducted several sensitivity tests and have analyzed a full Alternative Estimate.

Uncertainties Associated with Health Benefit Estimates

Within-Study Variation

Within-study variation refers to the precision with which a given study estimates the relationship between air quality changes and health effects. Health effects studies provide both a "best estimate" of this relationship plus a measure of the statistical uncertainty of the relationship. This size of this uncertainty depends on factors such as the number of subjects studied and the size of the effect being measured. The results of even the most well designed epidemiological studies are characterized by this type of uncertainty, though well-designed studies typically report narrower uncertainty bounds around the best estimate than do studies of lesser quality. In selecting health endpoints, we generally focus on endpoints where a statistically significant relationship has been observed, which by definition assures a reasonably tight confidence interval around the best estimate of the mean concentration-response relationship.

Across-study Variation

Across-study variation refers to the fact that different published studies of the same pollutant/health effect relationship typically do not report identical findings; in some instances the differences are substantial. These differences can exist even between equally reputable studies and may result in health effect estimates that vary considerably. Across-study variation can result from two possible causes. One possibility is that studies report different estimates of the single true relationship between a given pollutant and a health effect due to differences in study design, random chance, or other factors. For example, a hypothetical study conducted in New York and one conducted in Seattle may report different C-R functions for the relationship between PM and mortality, in part because of differences between these two study populations (e.g., demographics, activity patterns). Alternatively, study results may differ because these two studies are in fact estimating different relationships; that is, the same reduction in PM in New York and Seattle may result in different reductions in premature mortality. This may result from a number of factors, such as differences in the relative sensitivity of these two populations to PM pollution and differences in the composition of PM in these two locations.[22] In either case, where we identified multiple studies that are appropriate for estimating a given health effect, we generated a pooled estimate of results from each of those studies.

Application of C-R Relationship Nationwide

Whether this analysis estimated the C-R relationship between a pollutant and a given health endpoint using a single function from a single study or using multiple C-R functions from several studies, each C-R relationship was applied uniformly throughout the U.S. to generate health benefit estimates. However, to the extent that pollutant/health effect relationships are region-specific, applying a location-specific C-R function at all locations in the U.S. may result in overestimates of health effect changes in some locations and underestimates of health effect changes in other locations. It is not possible, however, to know the extent or direction of the overall effect on health benefit estimates introduced by application of a single C-R function to the entire U.S. This may be a significant uncertainty in the analysis, but the current state of the scientific literature does not allow for a region-specific estimation of health benefits.

Uncertainties in the PM Mortality Relationship

Health researchers have consistently linked air pollution, especially PM, with excess mortality. A substantial body of published scientific literature recognizes a correlation between elevated PM concentrations and increased mortality rates. However, there is much about this relationship that is still uncertain.[23] These uncertainties include:

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[22] PM is a mix of particles of varying size and chemical properties. The composition of PM can vary considerably from one region to another depending on the sources of particulate emissions in each region.

[23] The morbidity studies used in the Clear Skies Act benefits analysis may also be subject to many of the uncertainties listed in this

- ***Causality.*** A substantial number of published epidemiological studies recognize a correlation between elevated PM concentrations and increased mortality rates; however these epidemiological studies, by design, can not definitively prove causation. For the analysis of the Clear Skies Act, we assumed a causal relationship between exposure to elevated PM and premature mortality, based on the consistent evidence of a correlation between PM and mortality reported in the substantial body of published scientific literature.[24]

- ***Other Pollutants.*** PM concentrations are correlated with the concentrations of other criteria pollutants, such as ozone and CO, and it is unclear how much each of these pollutants may influence mortality rates. As discussed in Section II (Analytical Approach -- Health and Environmental Effects Modeling), recent studies have explored whether ozone may have mortality effects independent of PM, but we do not view the evidence as conclusive. To the extent that the C-R functions we use to evaluate the Clear Skies Act in fact capture mortality effects of other criteria pollutants besides PM, we may be overestimating the benefits of reductions in PM. However, since we are not providing separate estimates of the mortality benefits from the ozone and CO reductions likely to occur due to the Clear Skies Act, this approach represents a reasonable surrogate for the mortality effects of all criteria pollutant reductions.

- The benefit estimates presented in this document do not capture any additional short-term mortality impacts related to changes in exposure to ambient ozone. A recent analysis by Thurston and Ito (2001) reviewed previously published time series studies of the effect of daily ozone levels on daily mortality and found that previous EPA estimates of the short-term mortality benefits of the ozone NAAQS (U.S. EPA, 1997b) may have been underestimated by up to a factor of two. The authors hypothesized that much of the variability in published estimates of the ozone/mortality effect could be explained by how well each model controlled for the influence of weather, an important confounder of the ozone/mortality effect, and that earlier studies using less sophisticated approaches to controlling for weather consistently under-predicted the ozone/mortality effect. They found that models incorporating a non-linear temperature specification appropriate for the "U-shaped" nature of the temperature/mortality relationship (i.e., increased deaths at both very low and very high temperatures) produced ozone/mortality effect estimates that were both more strongly positive (a two percent increase in relative risk over the pooled estimate for all studies evaluated) and consistently statistically significant. Further accounting for the interaction effects between temperature and relative humidity produced even more strongly positive results. Inclusion of a PM index to control for PM/mortality effects had little effect on these results, suggesting an ozone/mortality

section.

[24] Much of this literature is summarized in the 1996 PM Criteria Document (US EPA, 1996a). There is much about this relationship that is still uncertain. As stated in preamble to the 1997 PM National Ambient Air Quality Standards (40 CFR 50, 1997), "the consistency of the results of the epidemiological studies from a large number of different locations and the coherent nature of the observed effects are suggestive of a likely causal role of ambient PM in contributing to the reported effects," which include premature mortality. The National Academy of Sciences, in their report on research priorities for PM (NAS, 1998), indicates that “there is a great deal of uncertainty about the implications of the findings [of an association between PM and premature mortality] for risk management, due to the limited scientific information about the specific types of particles that might cause adverse health effects, the contributions of particles of outdoor origin to actual human exposures, the toxicological mechanisms by which the particles might cause adverse health effects, and other important questions.” EPA acknowledges these uncertainties; however, for this analysis, we assume a causal relationship between exposure to elevated PM and premature mortality, based on the consistent evidence of a correlation between PM and mortality reported in the scientific literature.

relationship independent of that for PM. However, most of the studies examined by Ito and Thurston only controlled for PM_{10} or broader measures of particles and did not directly control for $PM_{2.5}$. As such, there may still be potential for confounding of $PM_{2.5}$ and ozone mortality effects, as ozone and $PM_{2.5}$ are highly correlated during summer months in some areas.[25] In its September 2001 advisory on the draft analytical blueprint for the second Section 812 prospective analysis, the SAB cited the Thurston and Ito study as a significant advance in understanding the effects of ozone on daily mortality and recommended re-evaluation of the ozone mortality endpoint for inclusion in the next prospective study (EPA-SAB-COUNCIL-ADV-01-004, 2001). Thus, recent evidence suggests that by not including an estimate of reductions in short-term mortality due to changes in ambient ozone, both the Base and Alternative Estimates may underestimate the benefits of implementation of the Clear Skies Act.

- ***Shape of the C-R Function.*** The shape of the true PM mortality C-R function is uncertain, but this analysis assumes the C-R function to have a log-linear form (as derived from the literature) throughout the relevant range of exposures. If this is not the correct form of the C-R function, or if certain scenarios predict concentrations well above the range of values for which the C-R function was fitted, avoided mortality may be mis-estimated.

- ***Regional Differences.*** As discussed above, significant variability exists in the results of different PM/mortality studies. This variability may reflect regionally specific C-R functions resulting from regional differences in factors such as the physical and chemical composition of PM. If true regional differences exist, applying the PM/Mortality C-R function to regions outside the study location could result in mis-estimation of effects in these regions.

- ***Exposure/Mortality Lags.*** It is currently unknown whether there is a time lag -- a delay between changes in PM exposures and changes in mortality rates -- in the chronic PM/mortality relationship. The existence of such a lag is important for the valuation of premature mortality incidence because economic theory suggests that benefits occurring in the future should be discounted. There is no specific scientific evidence of the existence or structure of a PM effects lag. However, current scientific literature on adverse health effects similar to those associated with PM (e.g., smoking-related disease) and the difference in the effect size between chronic exposure studies and daily mortality studies suggest that all incidences of premature mortality reduction associated with a given incremental change in PM exposure probably would not occur in the same year as the exposure reduction. The smoking-related literature also implies that lags of up to a few years are plausible. Adopting the lag structure used in the Tier 2/Gasoline Sulfur and Heavy-Duty Engine/Diesel Fuel RIAs and endorsed by the SAB (EPA-SAB-COUNCIL-ADV-00-001, 1999), we assume a five-year lag structure. This approach assumes that 25 percent of PM-related premature deaths occur in each of the first two years after the exposure and the rest occur in equal parts (approximately 17%) in each of the ensuing three years.

- ***Cumulative Effects.*** As a general point, we attribute the PM/mortality relationship in the

[25] Short-term ozone mortality risk estimates may also be affected by the statistical issue discovered by the Health Effects Institute (Greenbaum, 2002a). See page 24 for a more detailed discussion of this issue.

underlying epidemiological studies to cumulative exposure to PM. However, the relative roles of PM exposure duration and PM exposure level in inducing premature mortality remain unknown at this time.

Uncertainties Associated with Environmental and Ecosystem Effects Estimation

Our analysis of the Clear Skies Act includes a quantitative estimate of only two environmental effects: recreational visibility and ozone effects on agriculture. Scientific studies, however, have reliably linked atmospheric emissions of sulfur, nitrogen, and mercury to a much wider range of other environmental and ecological effects. Some of these effects are acute in nature, and some are longer-term and could take many years to manifest. The effects include the following:

- ***Acidic Deposition***. Effects associated with the deposition of sulfuric and nitric acid, formed in the atmosphere from sulfur dioxide and nitrogen oxide emissions, include direct toxic effects to plant leaves and aquatic organisms; progressive deterioration of soil quality; and chronic acidification of surface waters.

- ***Nitrogen Deposition***. Effects associated with deposition of atmospheric nitrogen compounds include saturation of terrestrial ecosystems and progressive nitrogen enrichment of coastal estuaries. The latter can lead to excessive algal growth, which can drastically reduce dissolved oxygen levels in aquatic ecosystems, and eventually diminish stocks of commercially and recreationally important fish and shellfish species.

- ***Mercury Deposition***: Effects associated with mercury deposition include direct toxic effects to animals, conservation of mercury in biogeochemical cycles, and accumulation of mercury in the food chain. Mercury in the food chain can eventually lead to developmental effects in children and/or the substantial curtailment of commercial and recreational fishing activities.

- ***Ozone:*** Tropospheric ozone, which forms from atmospheric reactions of nitrogen oxides and volatile organic compounds, can have direct toxic effects to plant leaves (including agriculture and commercial forests) and alter ecosystem wide patterns of energy flow and nutrient cycling. Only some ozone effects on agriculture are quantified in this analysis.

These effects are left unquantified for a variety of reasons, but mostly because of the complexity of modeling these effects and the major uncertainties in reliably quantifying the incremental effects of atmospheric emissions reductions on ecological endpoints.

Individually, many of these environmental effects may be relatively small in terms of their overall ecosystem and monetary importance, particularly in the near-term. Their cumulative and longer term effects, however, some of which may be largely unknown at this time, may be substantial. As a result, the omission of this broad class of benefits from our quantitative results likely causes our estimates to substantially understate the total benefits of the Clear Skies Act.

Uncertainties Associated with Economic Valuation of Benefits

Economic valuation of benefits often involves estimation of the willingness-to-pay of individuals to avoid harmful health or environmental effects. In most cases, there are no markets in which to directly observe WTP for these types of commodities. In some cases, we can rely on indirect market transactions, such as the implicit tradeoff of wages for on-the-job mortality risk among the working population, to estimate WTP. In other cases, we must rely on survey approaches to estimate WTP, usually through a variant of the contingent valuation approach, which generally involves directly questioning respondents for their WTP in hypothetical market situations. Regardless of the method used to estimate WTP, there are measurement errors, data inadequacies, and ongoing debates about the best practices for each method that contribute to the overall uncertainty of economic estimates.

General Benefits Transfer Considerations

For the Clear Skies benefits analysis, we do not have the time or resources to conduct primary economic research targeted at the specific air pollution-related benefits provided. As a result, we rely on the transfer of benefits estimates from existing studies. The conduct of "benefits transfer" exercises necessarily involves some uncertainties. These uncertainties can be reduced by careful consideration of the differences in the health risk or air pollution commodity and the study populations in the underlying economic literature versus the context of benefits conferred by the Clear Skies Act. For example, we make adjustments to the mortality valuation estimates to account for the estimated lag between exposure and manifestation of the effect, reflecting the basic economic tenet that individuals prefer benefits that occur sooner to those that occur later. We also make adjustments to account for expected changes in WTP over time as per capita income increases. We cannot adjust for all benefits transfer considerations, however, thus introducing additional uncertainty into our estimates.

Lack of Adequate Data or Methods

The lack of adequate data or methods to characterize WTP results in our inability to present monetized benefits of some categories of effects. For example, while studies exist that estimate the benefits of visibility improvements to individuals in the places they reside, these residential visibility studies are considered by some in the resource economics community to be less reliable because of the methods applied. In the case of residential visibility, we conduct sensitivity analyses to estimate the impact of this uncertainty in the reliability of methods. To the extent effects such as these represent categories of benefits that are truly valuable to the U.S. population, we have underestimated the total benefits of the Clear Skies Act.

Uncertainties Specific to Premature Mortality Valuation

The economic benefits associated with premature mortality are the largest category of monetized benefits of the Clear Skies Act.[26] In addition, in prior analyses EPA has identified valuation of mortality benefits as the largest contributor to the range of uncertainty in monetized

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[26]As noted in the methods section, it is actually reductions in mortality risk that are valued in a monetized benefit analysis. Individual WTPs for small reductions in mortality risk are summed over enough individuals to infer the value of a *statistical* life saved. 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."

benefits (see USEPA 1999a). Because of the uncertainty in estimates of the value of premature mortality avoidance, it is important to adequately characterize and understand the various types of economic approaches available for mortality valuation. Such an assessment also requires an understanding of how alternative valuation approaches reflect that some individuals may be more susceptible to air pollution-induced mortality, or reflect differences in the nature of the risk presented by air pollution relative to the risks studied in the relevant economic literature.

The health science literature on air pollution indicates that several human characteristics affect the degree to which mortality risk affects an individual. For example, some age groups appear to be more susceptible to air pollution than others (e.g., the elderly and children). Health status prior to exposure also affects susceptibility. At risk individuals include those who have suffered strokes or are suffering from cardiovascular disease and angina (Rowlatt, et al. 1998). An ideal benefits estimate of mortality risk reduction would reflect these human characteristics, in addition to an individual's willingness to pay (WTP) to improve one's own chances of survival plus WTP to improve other individuals' survival rates.[27] The ideal measure would also take into account the specific nature of the risk reduction commodity that is provided to individuals, as well as the context in which risk is reduced. To measure this value, it is important to assess how reductions in air pollution reduce the risk of dying from the time that reductions take effect onward, and how individuals value these changes. Each individual's survival curve, or the probability of surviving beyond a given age, should shift as a result of an environmental quality improvement. For example, changing the current probability of survival for an individual also shifts future probabilities of that individual's survival. This probability shift will differ across individuals because survival curves are dependent on such characteristics as age, health state, and the current age to which the individual is likely to survive.

Although a survival curve approach provides a theoretically preferred method for valuing the benefits of reduced risk of premature mortality associated with reducing air pollution, the approach requires a great deal of data to implement. The economic valuation literature does not yet include good estimates of the value of this risk reduction commodity. As a result, in this study we value avoided premature mortality risk using the value of statistical life approach in the Base Estimate, supplemented by valuation based on an age-adjusted value of statistical life estimate in the Alternative Estimate.

Other uncertainties specific to premature mortality valuation include the following:

- ***Across-study Variation***: The analytical procedure used in the main analysis to estimate the monetary benefits of avoided premature mortality assumes that the appropriate economic value for each incidence is a value from the currently accepted range of the value of a statistical life. This estimate is based on 26 studies of the value of mortal risks. There is considerable uncertainty as to whether the 26 studies on the value of a statistical life provide adequate estimates of the value of a statistical life saved by air pollution reduction. Although there is considerable variation in the analytical designs and data used in the 26 underlying studies, the majority of the studies involve the value of risks to a middle-aged working population. Most of the studies examine differences in wages of risky occupations, using a wage-hedonic approach. Certain characteristics of both the

[27] For a more detailed discussion of altruistic values related to the value of life, see Jones-Lee (1992).

population affected and the mortality risk facing that population are believed to affect the average willingness to pay (WTP) to reduce the risk. The appropriateness of a distribution of WTP estimates from the 26 studies for valuing the mortality-related benefits of reductions in air pollution concentrations therefore depends not only on the quality of the studies (i.e., how well they measure what they are trying to measure), but also on (1) the extent to which the risks being valued are similar, and (2) the extent to which the subjects in the studies are similar to the population affected by changes in pollution concentrations.

- ***Level of risk reduction***. The transferability of estimates of the value of a statistical life from the 26 studies to the Clear Skies Act analysis rests on the assumption that, within a reasonable range, WTP for reductions in mortality risk is linear in risk reduction. For example, suppose a study estimates that the average WTP for a reduction in mortality risk of 1/100,000 is $50, but that the actual mortality risk reduction resulting from a given pollutant reduction is 1/10,000. If WTP for reductions in mortality risk is linear in risk reduction, then a WTP of $50 for a reduction of 1/100,000 implies a WTP of $500 for a risk reduction of 1/10,000 (which is ten times the risk reduction valued in the study). Under the assumption of linearity, the estimate of the value of a statistical life does not depend on the particular amount of risk reduction being valued. This assumption has been shown to be reasonable provided the change in the risk being valued is within the range of risks evaluated in the underlying studies (Rowlatt et al. 1998).

- ***Voluntariness of risks evaluated***. Although there may be several ways in which job-related mortality risks differ from air pollution-related mortality risks, the most important difference may be that job-related risks are incurred voluntarily, or generally assumed to be, whereas air pollution-related risks are incurred involuntarily. There is some evidence[28] that people will pay more to reduce involuntarily incurred risks than risks incurred voluntarily. If this is the case, WTP estimates based on wage-risk studies may understate WTP to reduce involuntarily incurred air pollution-related mortality risks.

- ***Sudden versus protracted death***. A final important difference related to the nature of the risk may be that some workplace mortality risks tend to involve sudden, catastrophic events, whereas air pollution-related risks tend to involve longer periods of disease and suffering prior to death. Some evidence suggests that WTP to avoid a risk of a protracted death involving prolonged suffering and loss of dignity and personal control is greater than the WTP to avoid a risk (of identical magnitude) of sudden death. To the extent that the mortality risks addressed in this assessment are associated with longer periods of illness or greater pain and suffering than are the risks addressed in the valuation literature, the WTP measurements employed in the present analysis would reflect a downward bias.

IV. RESULTS

Base Estimate

[28]See, for example, Violette and Chestnut, 1983.

Exhibits 12 and 13 present a summary of health effects benefits resulting from improvements in air quality between the Base Case and the Clear Skies Act scenarios. Exhibit 12 presents the mean estimate of avoided health effects in 2010 and 2020 for each health endpoint included in the Base analysis. We estimate that reductions in exposure to fine PM and ozone due to the Clear Skies Act will result in over 6,000 fewer deaths in 2010 and nearly 12,000 fewer deaths in 2020, as well as nearly 4,000 fewer cases of chronic bronchitis in 2010 and over 7,000 fewer cases in 2020. In addition, 193,000 fewer asthma attacks are estimated to occur in 2010 and 373,000 fewer in 2020. Exhibit 13 summarizes the mean monetized health and visibility benefits due to the Clear Skies Act. As that exhibit shows, we estimate the monetized benefits of the Clear Skies Act in the continental United States will be $44 billion in 2010, including $43 billion in health benefits and $1 billion in recreational visibility benefits. In 2020, total benefits increase to $96 billion, with $93 billion in health benefits and $3 billion in recreational visibility benefits.

The results of our regional benefits analysis indicate that the vast majority of the health benefits of the Clear Skies Act are realized in the easternmost 39 states, including the states of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. We estimate total benefits of $44 billion in these 39 states in 2010, and $95 billion in 2020.

In addition to calculating the physical effects and monetary impacts of the Clear Skies Act, we also estimated the distribution of particulate matter air quality improvements that will be experienced by the US population. Exhibit 14 illustrates the numbers of individuals and the percent of the US population that they represent that will experience changes in ambient particulate matter concentrations in 2010 and 2020. As indicated in the table, the Clear Skies Act yields relatively modest air quality improvements for about one-fourth of the US population (i.e., changes in PM concentrations of less than 0.25 $\mu g/m^3$), in both 2010 and 2020, but more substantial improvements for a large percentage of the population, including improvements in excess of 2 $\mu g/m^3$ for more than 24 million individuals by 2020.

Exhibit 12
Change in Incidence of Adverse Health Effects Associated with Reductions in Particulate Matter and Ozone Due to the Clear Skies Act – 48 State U.S. Population (avoided cases per year)

		2010	2020
Endpoint	**Pollutant**	**mean**	**mean**
Mortality			
Chronic Exposure, Ages 30 and Older	$PM_{2.5}$	6,400	11,900
Chronic Illness			
Chronic Bronchitis	PM_{10}, $PM_{2.5}$	3,900	7,400
Hospitalization / ER Visits			
COPD Admissions	PM_{10}	700	1,300
Pneumonia Admissions	PM_{10}	800	1,500
Cardiovascular Admissions	PM_{10}	2,000	3,700
Asthma Admissions	$PM_{2.5}$	600	1,200
All Respiratory Admissions	Ozone	500	1,000
Dysrhythmia Admissions	Ozone	100	300
Emergency Room Visits for Asthma	PM_{10} and Ozone	1,600	2,900
Hospitalization / ER Visits Subtotal		6,300	11,900
Minor Respiratory Illness and Symptoms			
Acute Bronchitis	$PM_{2.5}$	12,900	23,800
Upper Respiratory Symptoms	PM_{10}	141,000	262,000
Lower Respiratory Symptoms	$PM_{2.5}$	141,000	260,000
Asthma Attacks	PM_{10} and Ozone	195,000	373,000
Work Loss Days	$PM_{2.5}$	1,100,000	2,060,000
Minor Restricted Activity Days (minus asthma attacks)	$PM_{2.5}$ and Ozone	6,400,000	12,100,000
Minor Respiratory Illness and Symptoms Subtotal		8,000,000	15,100,000

Totals may not sum due to rounding.

Exhibit 13 Results of Human Health and Welfare Benefits Valuation for the Clear Skies Act (Particulate Matter and Ozone Reductions Only)			
Endpoint	**Pollutant**	**Monetary Benefits in 2010, mean (Millions of 1999$)**	**Monetary Benefits in 2020, mean (Millions of 1999$)**
Mortality			
Chronic Exposure, Ages 30 and older	$PM_{2.5}$	$41,400* $38,900**	$88,900* $83,500**
Chronic Illness			
Chronic Bronchitis	PM_{10} $PM_{2.5}$	$1,500	$3,200
Hospitalization			
COPD Admissions	PM_{10}	$8	$16
Pneumonia Admissions	PM_{10}	$12	$23
Cardiovascular Admissions	PM_{10}	$37	$69
Asthma Admissions	$PM_{2.5}$	$4	$8
All Respiratory Admissions	Ozone	$6	$14
Dysrhythmia Admissions	Ozone	$1	$3
Emergency Room Visits for Asthma	PM_{10} and Ozone	$0.4	$1
Hospitalization / ER Visits Subtotal		$69	$130
Minor Respiratory Illness and Symptoms			
Acute Bronchitis	$PM_{2.5}$	$1	$1
Upper Respiratory Symptoms	PM_{10}	$4	$7
Lower Respiratory Symptoms	$PM_{2.5}$	$2	$4
Work Loss Days	$PM_{2.5}$	$120	$220
Minor Restricted Activity Days (minus asthma attacks)	$PM_{2.5}$ and Ozone	$325	$630
Minor Respiratory Illness and Symptoms Subtotal		$450	$860
Total Health Benefits in 2020		$43,400* $40,900**	$93,000* $87,600**
Welfare			
Recreational Visibility; CA, SW, and SE park regions	PM	$900	$2,800
Agriculture	Ozone	$47	$56
Worker Productivity	Ozone	$55	$130
Total Benefits in 2020		$44,000* $41,500**	$96,000* $90,600**

Totals may not sum due to rounding.
* Results calculated using three percent discount rate as recommended by EPA's *Guidelines for Economic Analysis* (US EPA, 2000a).
** Results calculated using seven percent discount rate as recommended by OMB Circular A-94 (OMB, 1992). Total benefit numbers reflect use of three percent discount rate.

Exhibit 14
Distribution of $PM_{2.5}$ Air Quality Improvements Over 2010 and 2020 Population Due to the Clear Skies Act

Change in Annual Mean $PM_{2.5}$ Concentrations ($\mu g/m^3$)	2010 Population		2020 Population	
	Number (millions)	Percent (%)	Number (millions)	Percent (%)
$0 < \Delta PM_{2.5}$ Conc ≤ 0.25	83.4	28.2%	80.6	25.1%
$0.25 < \Delta PM_{2.5}$ Conc ≤ 0.50	51.8	17.5%	18.4	5.7%
$0.50 < \Delta PM_{2.5}$ Conc ≤ 0.75	70.2	23.8%	29.0	9.0%
$0.75 < \Delta PM_{2.5}$ Conc ≤ 1.0	49.0	16.6%	44.0	13.7%
$1.0 < \Delta PM_{2.5}$ Conc ≤ 1.25	36.5	12.4%	49.9	15.5%
$1.25 < \Delta PM_{2.5}$ Conc ≤ 1.50	3.9	1.3%	21.8	6.8%
$1.50 < \Delta PM_{2.5}$ Conc ≤ 1.75	0.7	0.2%	26.2	8.2%
$1.75 < \Delta PM_{2.5}$ Conc ≤ 2.0	-	-	26.7	8.3%
$\Delta PM_{2.5}$ Conc > 2.0	-	-	24.1	7.5%

* Totals may not sum due to rounding.

Alternative Estimate

Exhibits 15 and 16 present the results of the Alternative calculations. Exhibit 15 presents the mean estimate of avoided health effects in 2010 and 2020 for each health endpoint included in the Base analysis. Under the Alternative Estimate, the number of avoided cases of chronic bronchitis, hospital and ER visits, and minor respiratory illnesses and symptoms is the same as the Base. The Alternative projects that reductions in exposure to fine PM and ozone due to the Clear Skies Act will result in 3,800 avoided premature deaths in 2010 and nearly 7,200 avoided premature deaths in 2020. The omission of long-term impacts of particulate matter on mortality accounts for approximately 40 percent reduction in the estimate of avoided premature mortality in the Alternative Estimate relative to the Base Estimate.

Exhibit 16 summarizes the mean monetized health and visibility benefits of the Alternative Estimate, which will be $6.3 billion in 2010 and $14.1 billion in 2020. The 40 percent reduction in mortality under the Alternative Estimate and the difference in valuation of premature mortality and chronic bronchitis explain the difference in benefits between these two approaches. Even using the more conservative Alternative Estimate benefit projections, however, the benefits of Clear Skies still outweigh the costs of $3.7 billion in 2010 and $6.5 billion in 2020. It is also important to note that both the Alternative and Base Estimate are likely to underestimate the benefits of this proposal because of the many environmental and health effects that we were unable to quantify in this analysis.

Exhibit 15 Alternative Estimate of the Change in Incidence of Adverse Health Effects Associated with Reductions in Particulate Matter and Ozone Due to the Clear Skies Act in 2010 – 48 State U.S. Population (avoided cases per year)			
		2010	**2020**
Endpoint	**Pollutant**	**mean**	**mean**
Mortality			
Short-Term Exposure, Non-COPD Related, Ages 65 and Over	$PM_{2.5}$	2,600	4,900
Short-Term Exposure, Non-COPD Related, Ages 64 and Under	$PM_{2.5}$	800	1,500
Short-Term Exposure, COPD Related, Ages 65 and Over	$PM_{2.5}$	360	670
Short-Term Exposure, COPD Related, Ages 64 and Under	$PM_{2.5}$	57	110
Short-Term Mortality Subtotal		3,800	7,200
Chronic Illness			
Chronic Bronchitis	PM_{10}, $PM_{2.5}$	3,900	7,400
Hospitalization / ER Visits			
COPD Admissions	PM_{10}	680	1,300
Pneumonia Admissions	PM_{10}	830	1,500
Cardiovascular Admissions	PM_{10}	2,000	3,700
Asthma Admissions	$PM_{2.5}$	630	1,200
All Respiratory Admissions	Ozone	500	1,000
Dysrhythmia Admissions	Ozone	100	300
Emergency Room Visits for Asthma	PM_{10} and Ozone	1,600	2,900
Hospitalization / ER Visits Subtotal		6,300	11,900
Minor Respiratory Illness and Symptoms			
Acute Bronchitis	$PM_{2.5}$	12,900	23,800
Upper Respiratory Symptoms	PM_{10}	141,000	262,000
Lower Respiratory Symptoms	$PM_{2.5}$	141,000	260,000
Asthma Attacks	PM_{10} and Ozone	193,000	373,000
Work Loss Days	$PM_{2.5}$	1,100,000	2,060,000
Minor Restricted Activity Days (minus asthma attacks)	$PM_{2.5}$ and Ozone	6,400,000	12,100,000
Minor Respiratory Illness and Symptoms Subtotal		8,000,000	15,100,000

Totals may not sum due to rounding.

Exhibit 16
Alternative Human Health and Welfare Benefits Estimates for the Clear Skies Act
(Particulate Matter and Ozone Reductions Only)

	Monetary Benefits (in millions of 1999$) Mean, 2010	**Monetary Benefits (in millions of 1999$) Mean, 2020**
Mortality		
Short-Term Exposure, Non-COPD Related, Ages 65 and Over	$3,600	$7,800
Short-Term Exposure, Non-COPD Related, Ages 64 and Under	$700	$1,500
Short-Term Exposure, COPD Related, Ages 65 and Over	$55	$120
Short-Term Exposure, COPD Related, Ages 64 and Under	$5	$12
Short-Term Mortality Subtotal	$4,400* $5,100**	$9,400* $10,900**
Chronic Illness		
Chronic Bronchitis	$420	$790
Hospitalization		
COPD Admissions	$8	$16
Pneumonia Admissions	$12	$23
Cardiovascular Admissions	$37	$69
Asthma Admissions	$4	$8
All Respiratory Admissions	$6	$14
Dysrhythmia Admissions	$1	$3
Emergency Room Visits for Asthma	$0.4	$1
Hospitalization / ER Visits Subtotal	$69	$130
Minor Respiratory Illness and Symptoms		
Acute Bronchitis	$1	$1
Upper Respiratory Symptoms	$4	$7
Lower Respiratory Symptoms	$2	$4
Work Loss Days	$120	$220
Minor Restricted Activity Days (minus asthma attacks)	$325	$630
Minor Respiratory Illness and Symptoms Subtotal	$450	$860
Total Health Benefits in 2020	$5,300* $6,000**	$11,200* $12,700**
Welfare		
Recreational Visibility; CA, SW, and SE park regions	$900	$2,800
Agriculture	$47	$56
Worker Productivity	55	130
Total Benefits in 2020	$6,300* $7,000**	$14,100* $15,600**

* Results calculated using three percent discount rate as recommended by EPA's *Guidelines for Economic Analysis* (US EPA, 2000a).
** Results calculated using seven percent discount rate as recommended by OMB Circular A-94 (OMB, 1992).
Totals may not sum due to rounding.

Sensitivity Analyses

The Base Estimate is based on our current interpretation of the scientific and economic literature; its judgments regarding the best available data, models, and modeling methodologies; and the assumptions it considers most appropriate to adopt in the face of important uncertainties. The majority of the analytical assumptions used to develop the Base Estimate have been reviewed and approved by EPA's Science Advisory Board (SAB). However, we recognize that data and modeling limitations as well as simplifying assumptions can introduce significant uncertainty into the benefit results and that reasonable alternative assumptions exist for some inputs to the analysis, such as the mortality C-R functions.

To address these concerns, we supplement our Base Estimate of benefits with a series of sensitivity calculations that make use of other sources of concentration-response and valuation data for key benefits categories. These sensitivity calculations are conducted only for the Base Estimate and not for the Alternative Estimate. First we applied three alternative concentration-response (C-R) functions to estimate premature mortality incidence. Although we used the Krewski, et al. (2000) mean-based ("PM2.5(DC), All Causes") model exclusively to derive our Base Estimate of avoided premature mortality, this analysis also examined the sensitivity of the benefit results to the selection of alternative C-R functions for premature mortality. We used three sources of alternative C-R functions for this sensitivity analysis: (1) an alternative specification of the Pope/ACS model from Krewski, et al. (2000) that adjusted for spatial correlation in the dataset; (2) the original Pope/ACS model; and (3) the Krewski et al. "Harvard Six Cities" estimate. Exhibits 15 and 16 present the results of these sensitivity analyses for 2010 and 2020, respectively.

The first alternative C-R function is based on the relative risk of 1.16 from the "Fine Particles Alone, Regional Adjustment Random Effects" model reported in Table 46 of the HEI report. Commentary by an independent review panel noted that "a major contribution of the [HEI] Reanalysis Project is the recognition that both pollutant variables and mortality appear to be spatially correlated in the ACS data set. If not identified and modeled correctly, spatial correlation could cause substantial errors in both the regression coefficients and their standard errors (HEI, 2000)." This C-R function is a reasonable specification to explore the impact of adjustments for broad regional correlations. However, the HEI report noted that the spatial adjustment methods "may have over adjusted the estimated effect for regional pollutants such as fine particles and sulfate compared with the effect estimates for more local pollutants such as sulfur dioxide." Thus, the estimates of avoided incidences of premature mortality based on this C-R function may underestimate the true effect. (Note that this C-R function is based on the original air quality dataset used in the ACS study, covering 50 cities, and used the median $PM_{2.5}$ levels rather than mean $PM_{2.5}$ as the indicator of exposure.)

For comparison with earlier benefits analyses, such as the first Section 812 Prospective Analysis, we also include estimates of avoided incidences of premature mortality based on the original ACS/Pope et al. (1995) analysis in the second row of Exhibit 15 and 16. The third row of Exhibit 17 shows the Krewski, et al. "Harvard Six Cities" estimate of mortality. The Krewski-Harvard Six Cities study used a smaller sample of individuals from fewer cities than the study by Pope, et al.; however, it features improved exposure estimates, a slightly broader study population (adults aged 25 and older), and a follow-up period nearly twice as long as that of Pope, et al. The SAB has noted that "the [Harvard Six Cities] study had better monitoring with less measurement error than did most other studies" (EPA-SAB-COUNCIL-ADV-99-012, 1999).

Second, we use an alternative valuation procedure to estimate the value of avoided premature mortality, with explicit consideration of the expected age of mortality incidence associated with air pollution exposure. Age-specific VSL adjustment factors can be derived from a series of contingent valuation studies conducted in the United Kingdom to evaluate WTP for road safety improvements that reduce mortality risk. The two available sources, both authored by Michael Jones-Lee, derive significantly differing adjustment factors, and reflect reflecting the overall uncertainty within the literature about age-specific VSL adjustments. The results of this alternative calculation reduce the overall Base Estimate for the Clear Skies Act by 43 percent for the more extreme adjustment derived from Jones-Lee (1989), and by 9 percent for the less extreme adjustment derived from Jones-Lee (1993), as summarized in Exhibits 15 and 16 below. The specific adjustment procedure applied is described in more detail in the Heavy-Duty Engine/Diesel Fuel RIA (U.S. EPA, 2000b).

Third, as noted in the section above on visibility valuation, we chose not to include in our Base Estimate the valuation of residential visibility or valuation of recreational visibility at Class I areas outside of the study regions examined in the Chestnut and Rowe (1990a, 1990b) study. The last three rows of Exhibits 17 and 18 summarize the impact of applying the existing visibility valuation literature more broadly than in our Base Estimate.

Exhibit 17 Key Sensitivity Analyses for the Clear Skies Act in 2010[A]				
Description of Basis for Analysis			**Avoided Incidences**	**Impact on Base Benefits Estimate Adjusted for Growth in Real Income (billion 1999$)**
Concentration-Response Functions for PM-related Premature Mortality				
1	Krewski/ACS Study Regional Adjustment Model[B]		7,300	+$5.8 (+13%)
2	Pope/ACS Study[C]		7,700	+$8.5 (+20%)
3	Krewski/Harvard Six-City Study[D]		18,800	+$80 (+182%)
Methods for Valuing Reductions in Incidences of PM-related Premature Mortality				
Value of avoided premature mortality incidences based on age-specific VSL.[E]		Jones-Lee (1989)	6,400	-$18.6 (-42%)
		Jones-Lee (1993)	6,400	-$3.8 (-9%)
Expanded Scope of Visibility Valuation				
1	Recreational visibility for all Class I areas		-	+$0.5 (+1%)
2	Residential visibility, 31 Eastern states		-	+$1.0 (+2%)
3	Residential visibility, all US		-	+$1.2 (+3%)

[A] These results indicate the sensitivity of the primary benefits estimate to alternative assumptions; results reflect the use of a three percent discount rate, where appropriate.
[B] This C-R function is included as a reasonable specification to explore the impact of adjustments for broad regional correlations, which have been identified as important factors in correctly specifying the PM mortality C-R function.
[C] The Pope et al. C-R function was used to estimate reductions in premature mortality for the Tier 2/Gasoline Sulfur benefits analysis. It is included here to provide a comparable estimate for the Clear Skies Act.
[D] The Krewski et al. "Harvard Six-cities Study" estimate is included because the Harvard Six-cities Study featured improved exposure estimates, a slightly broader study population (adults aged 25 and older), and a follow-up period nearly twice as long as that of Pope, et al. and as such provides a reasonable alternative to the Base Estimate.
[E] Jones-Lee (1989) provides an estimate of age-adjusted VSL based on a finding that older people place a much lower value on mortality risk reductions than middle-age people. Jones-Lee (1993) provides an estimate of age-adjusted VSL based on a finding that older people value mortality risk reductions only somewhat less than middle-aged people.

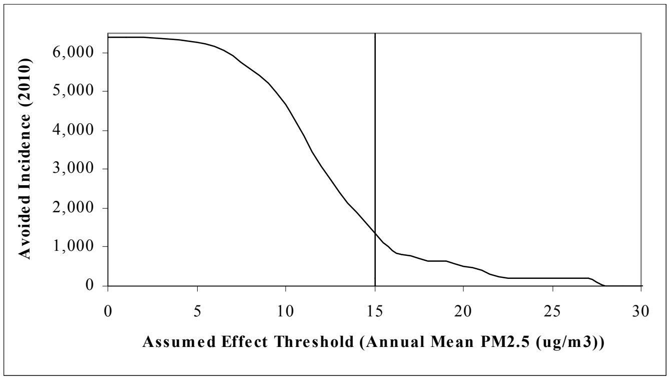
Exhibit 18 Key Sensitivity Analyses for the Clear Skies Act in 2020[A]				
Description of Basis for Analysis			**Avoided Incidences**	**Impact on Base Benefits Estimate Adjusted for Growth in Real Income (billion 1999$)**
Concentration-Response Functions for PM-related Premature Mortality				
1	Krewski/ACS Study Regional Adjustment Model[B]		13,400	+$11 (+11%)
2	Pope/ACS Study[C]		14,200	+$17 (+17%)
3	Krewski/Harvard Six-City Study[D]		35,000	+$171 (+179%)
Methods for Valuing Reductions in Incidences of PM-related Premature Mortality				
Value of avoided premature mortality incidences based on age-specific VSL.[E]		Jones-Lee (1989)	11,900	-$40 (-41%)
		Jones-Lee (1993)	11,900	-$8.1 (-8%)
Expanded Scope of Visibility Valuation				
1	Recreational visibility for all Class I areas		-	+$1.1 (+1%)
2	Residential visibility, 31 Eastern states		-	+$2.8 (+3%)
3	Residential visibility, all US		-	+$3.2 (+3%)

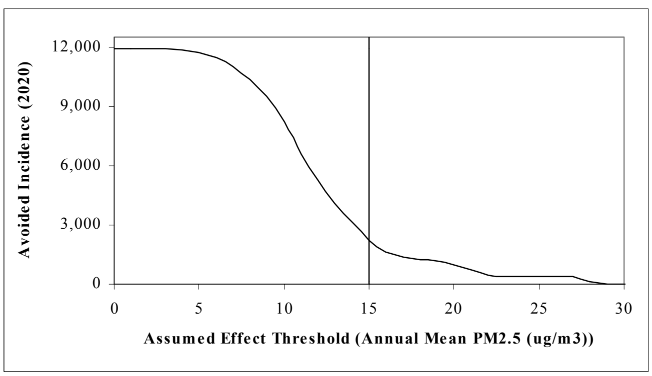
[A] These results indicate the sensitivity of the primary benefits estimate to alternative assumptions; results reflect the use of a three percent discount rate, where appropriate.
[B] This C-R function is included as a reasonable specification to explore the impact of adjustments for broad regional correlations, which have been identified as important factors in correctly specifying the PM mortality C-R function.
[C] The Pope et al. C-R function was used to estimate reductions in premature mortality for the Tier 2/Gasoline Sulfur benefits analysis. It is included here to provide a comparable estimate for the Clear Skies Act.
[D] The Krewski et al. "Harvard Six-cities Study" estimate is included because the Harvard Six-cities Study featured improved exposure estimates, a slightly broader study population (adults aged 25 and older), and a follow-up period nearly twice as long as that of Pope, et al. and as such provides a reasonable alternative to the Base Estimate.
[E] Jones-Lee (1989) provides an estimate of age-adjusted VSL based on a finding that older people place a much lower value on mortality risk reductions than middle-age people. Jones-Lee (1993) provides an estimate of age-adjusted VSL based on a finding that older people value mortality risk reductions only somewhat less than middle-aged people.

Fourth, we conducted a quantitative sensitivity test on one aspect of the PM-mortality dose-response function. Although the consistent advice from EPA's Science Advisory Board has been to model premature mortality associated with PM exposure as a non-threshold effect, that is, with harmful effects to exposed populations regardless of the absolute level of ambient PM concentrations, some analysts have hypothesized the presence of a threshold relationship. The nature of the hypothesized relationship is that there might exist a PM concentration level below which further reductions no longer yield premature mortality reduction benefits. EPA does not necessarily endorse any particular threshold. Nonetheless, Exhibit 19 illustrates how our estimates of the number of premature mortalities in the Base Estimate might change under a range of alternative assumptions for a PM mortality threshold. If, for example, there were no benefits of reducing PM concentrations below the proposed PM2.5 standard of 15 $\mu g/m^3$, our estimate of the total number of premature mortalities in 2020 would be reduced by approximately 80 percent, from approximately 12,000 annually to approximately 2,200 annually.

One important assumption that we adopted for the threshold sensitivity analysis is that no adjustments are made to the shape of the concentration-response function above the assumed threshold. Instead, thresholds were applied by simply assuming that any changes in ambient concentrations below the assumed threshold would have no impacts on the incidence of premature mortality. If there were actually a threshold, then the shape of the C-R function above the threshold would likely change.

Exhibit 18
Sensitivity Analysis: Effect of Thresholds on Estimated 2010 and 2020 Clear Skies Analysis PM-Related Mortality





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Addendum 1 – May 2003

The Administration continues to improve its benefit methods as new information becomes available. Based on new methods developed for the proposed Nonroad Diesel Engine Rule, the Administration has recalculated the Alternative Estimate for the 2002 Clear Skies Act. Using these new methods, the total benefits of the Alternative estimate increased from $14 billion to $19 billion in 2020. For 2010, these benefits increased from $6 billion to $8 billion. A detailed description of the new methods for the Alternative Estimate can be found in Chapter 9 of the *Draft Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines* released in April 2003 (http://www.epa.gov/nonroad/r03008.pdf).

EPA is currently analyzing the 2003 Clear Skies Act using updated methods and assumptions for modeling emissions, air quality, and benefits – including the new Alternative Estimate methods. All Base and Alternative numbers reflected in this document will be revised as the results of the 2003 Clear Skies analysis become available.