Chapter 10: Benefit-Cost Analysis

10.1 Introduction

This chapter contains EPA's analysis of the economic benefits of the Large SI/Recreational Vehicle rule. The analysis presented here attempts to answer three questions

- What are the physical health and welfare effects of changes in ambient air quality resulting from reductions in nitrogen oxides (NOx), hydrocarbons (HC) (including air toxics), carbon monoxide (CO), and particulate matter (PM) emissions?
- What is the value placed on these emission reductions by U.S. citizens as a whole?
- How do these estimated benefits compare to the estimated costs associated with this rule?

In the benefits analysis, we calculate a limited set of PM-related health benefits (our base-case estimate). In this part of the analysis, we estimate nationwide PM health effects benefits associated with reduction of Nox and direct PM emissions from Large SI only. Reductions related to ATVs, OHMs, snowmobiles and recreational marine diesel are not quantified. This analysis is based on estimated reductions in NOx and PM emissions and uses a benefits transfer technique to determine the changes in human health and welfare, both in terms of physical effects and monetary value

These analyses yield a stream of monetized benefits which we compare to the costs of the standards. It is important to note that there are significant categories of benefits associated with the control program which cannot be monetized (or in many cases even quantified), including visibility, ozone health benefits, ecological effects, most species of air toxics' health and ecological effects. We identify these benefits in the discussion below and carry them through our estimates as nonmonetized health benefits.

10.2 General Methodology

10.2.1 PM Methodology - Benefits Transfer

In performing the analysis for the PM benefits, we relied on the results of a similar analysis performed for our emission controls for on-highway heavy-duty engines (called the HD07 rule.[1] see 99 FR 5002, January 18, 2001). This approach was necessary due to time and

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[1] Additional information about the Regulatory Model System for Aerosols and Deposition (REMSAD) and our modeling protocols can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. A-2000-01, Document No. A-II-13.

resource constraints. To apply that analysis to this control program, we used a benefits transfer technique, described below. 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, adjustments are made 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. Additional information on the technique used can be found in Hubbell 2002 memorandum to the Docket (Docket A-2000-01, Document IV-A-146).

The HD07 analysis followed the same general methodology used in the benefits analysis for the passenger vehicle Tier 2/Gasoline Sulfur final rule[2] and other EPA air benefits reports, with routine updates in response to public comment and to reflect advances in modeling and the literature for economics and health effects. This analysis also reflects the advice of its independent Science Advisory Board (SAB) in determining the health and welfare effects considered in the benefits analysis and in establishing the most scientifically valid measurement and valuation techniques.

10.2.2 CO and Air Toxics Methodology : WTP

In this component of the analysis, we discuss the benefits of reducing air toxics pollution from vehicles subject to the rule. The only segment for which willingness to pay for reductions in pollution were reported in the literature was for use-values for snowmobiles; however, the estimates pertained only to use value and were not judged to be reliable. There were no studies estimating the changes in consumer surplus to other non-snowmobilers such as cross-country skiers, nature enthusiasts, and residents near where snowmobiles are operated. We are not able to estimate the value of changes in air toxics or CO from other engines subject to this rule.

10.2.3 Benefits Quantification

We use the term *benefits* to refer to any and all positive effects of emissions changes on social welfare that we expect to result from the final rule. We use the term environmental costs (also commonly referred to as “disbenefits”) to refer to any and all negative effects of emissions changes on social welfare that result from the final rule. We include both benefits and environmental costs in this analysis. Where it is possible to quantify benefits and environmental costs, our measures are those associated with economic surplus in accepted applications of welfare economics. They measure the value of changes in air quality by estimating (primarily through benefits transfer) the willingness of the affected population to pay for changes in environmental quality and associated health and welfare effects.

This document is also available at http://www.epa.gov/otaq/disel.htm#documents. Information can also be found in the docket for the HD07 rulemaking: A-99-06.

[2] US EPA. Regulatory Impact Analysis: Control of Air Pollution from New Motor Vehicles: Tier 2 Emission Standards. Report No EPA420-R-99-023. December 1999. A copy of this document can be found in Docket A-99-06, Document IV-A-09.

Not all the benefits of the rule can be estimated with sufficient reliability to be quantified and included in monetary terms. The omission of these items from the total of monetary benefits reflects our inability to measure them. It does not indicate their lack of importance in the consideration of the benefits of this rulemaking.

This analysis presents estimates of the potential benefits from the Large SI/Recreational Vehicle rule expected to occur in 2030 as well as a stream of benefits and net present value from 2002 to 2030. The predicted emissions reductions that will result from the rule have yet to occur, and therefore the actual changes in human health and welfare outcomes to which economic values are ascribed are predictions. These predictions are based on the best available scientific evidence and judgment, but there is unavoidable uncertainty associated with each step in the complex process between regulation and specific health and welfare outcomes.

Changes in ambient concentrations will lead to new levels of environmental quality in the U.S., reflected both in human health and in non-health welfare effects. Thus, the predicted changes in ambient air quality serve as inputs into functions that predict changes in health and welfare outcomes. We use the term “endpoints” to refer to specific effects that can be associated with changes in air quality. Table 10.2-1 lists the human health and welfare effects identified for changes in air quality as they related to ozone, PM, CO, and HC.[3] This list includes both those effects quantified (and/or monetized) in this analysis and those for which we are unable to provide quantified estimates.

For changes in risks to human health from changes in PM, quantified endpoints include changes in mortality and in a number of pollution-related non-fatal health effects. Only the benefits related to changes in NOx-related PM and directly emitted PM were estimated for Large SI. HC-related PM and any PM-related benefits for recreational marine, ATVs, OHMs, and snowmobiles were not estimated because of uncertainties with the benefits transfer to those categories and due to lack of information about HC-related PM from the original data set.

The benefits related to changes in CO and HC are not directly quantified for our primary analysis due to a lack of direct estimates of willingness to pay or appropriate exposure and air quality models for these pollutants.

Table 10.2-1
Human Health and Welfare Effects of Pollutants Affected by the Large SI/Recreational Vehicle Rule

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[3] The HC listed in Table 10.2-1 are also listed as hazardous air pollutants in the Clean Air Act. We are not able to quantify their direct effects. To the extent that they are precursors to ozone or PM, they are included in our quantitative results.

Pollutant/Effect	Primary Quantified and Monetized Effects[A]	Unquantified Effects
Ozone/Health	Not quantified in this analysis	Minor restricted activity days Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma Non-asthma respiratory emergency room visits Asthma symptoms Chronic asthma[C] Premature mortality[D] 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
Ozone/Welfare	Not quantified in this analysis	Decreased worker productivity Decreased yields for commercial crops Decreased commercial forest productivity Decreased yields for fruits and vegetables Decreased yields for other commercial and non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Damage to ecosystem functions
PM/Health	Premature mortality Bronchitis - chronic and acute Hospital admissions - respiratory and cardiovascular[B] Emergency room visits for asthma Asthma attacks Lower and upper respiratory illness Minor restricted activity days Work loss days	Infant mortality Low birth weight Changes in pulmonary function Chronic respiratory diseases other than chronic bronchitis Morphological changes Altered host defense mechanisms Cancer Non-asthma respiratory emergency room visits
PM/Welfare	Not quantified in this analysis	Visibility in areas where people live, work and recreate Visibility in Class I national parks and forest areas Household soiling Materials damage

Pollutant/Effect	Primary Quantified and Monetized Effects[A]	Unquantified Effects
Nitrogen and Sulfate Deposition/ Welfare	Not quantified in this analysis	Impacts of acidic sulfate and nitrate deposition on commercial forests Impacts of acidic deposition on commercial freshwater fishing Impacts of acidic deposition on recreation in terrestrial ecosystems Impacts of nitrogen deposition on commercial fishing, agriculture, and forests Impacts of nitrogen deposition on recreation in estuarine ecosystems Costs of nitrogen controls to reduce eutrophication in estuaries Reduced existence values for currently healthy ecosystems
NOx/Health	Not quantified in this analysis	Lung irritation Lowered resistance to respiratory infection Hospital Admissions for respiratory and cardiac diseases
CO/Health	Not quantified in this analysis As a supplemental calculation, some behavior effects (choice-reaction time) are quantified for one category for which an exposure model was available	Premature mortality[B] Behavioral effects Hospital admissions - respiratory, cardiovascular, and other Other cardiovascular effects Developmental effects Decreased time to onset of angina Non-asthma respiratory ER visits
HCs [E] Health	Not quantified in this analysis As a supplemental calculation, some behavior effects (choice-reaction time and toluene) are quantified for one category for which an exposure model was available	Cancer (diesel PM, benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucous membranes (formaldehyde) Respiratory and respiratory tract Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation & congestion (acrolein)

Pollutant/Effect	Primary Quantified and Monetized Effects[A]	Unquantified Effects
HCs [E] Welfare	Not quantified in this analysis	Direct toxic effects to animals Bioaccumulation in the food chain

[A] Primary quantified and monetized effects are those included when determining the base-case estimate of total monetized benefits of the Large SI/Recreational Vehicle rule.

[B] 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 and reduced lower respiratory symptoms. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies 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 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.

[C] While no causal mechanism has been identified linking new incidences of chronic asthma to ozone exposure, an epidemiological study shows a statistical association between long-term exposure to ozone and incidences of chronic asthma in some non-smoking men (McDonnell, et al., 1999).

[D] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the American Cancer Society (ACS)/ Krewski, et al., 2000 C-R function we use for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants (ACS/ Krewski, et al., 2000).

[E] Many of the hydrocarbons (HCs) listed in the table are also hazardous air pollutants listed in the Clean Air Act.

This remainder of this chapter proceeds as follows: in Sections 10.3, we describe the categories of benefits that are estimated, present the techniques and inputs that are used, and provide a discussion of how we incorporate uncertainty into our analysis. In Section 10.4, we briefly discuss the CO and air toxics benefits in a qualitative manner. In Section 10.5, we report our estimates of total monetized benefits.

10.3 PM-Related Health Benefits Estimation

10.3.1 Emissions Inventory Implications

The national inventories for NOx, HC, CO and PM have already been presented and discussed in Chapters 1 and 6 and in the supporting documents referenced in those chapters. Interested readers desiring more information about the inventory methodologies or results should consult that chapter for details. This section explains the specific inventories that were used in our quantitative estimates of benefits and the implications of those inventories related to interpreting results.

As noted in the previous section, this analysis focuses on the PM-related health benefits from emission reductions from Large SI engines only. To quantify these PM-related health benefits, we used NOx and direct PM emission changes (both reductions and increases, where applicable) for the categories Large SI. Our underlying air quality modeling which forms the basis for the transfer technique considers NOx as a precursor for both PM and ozone; thus, oxidant chemistry in the model would not lead to over-estimation of secondary PM formation. We did not include HC-related PM because we do not currently have an appropriate transfer technique.

We did not quantify the NOx, direct PM, or HC-related PM benefits for ATVs, OHMs, recreational marine diesels or snowmobiles because in our judgement there are substantial uncertainties in making the transfer from the on-highway vehicle modeling to these categories. This is because their operating characteristics and the locations in which these nonroad engines are used can be very different from on-highway vehicles. We had more reason to believe that the distribution of vehicles with respect to human populations was more similar for Large SI. However, in the analyses of alternatives, we present a sensitivity calculation for ATVs, noting the large uncertainties inherent in that application of this technique.

As described in the previous chapters of this Regulatory Support Document, the emission controls for Large SI engines and recreational vehicles begin at various times and in some cases phase in over time. This means that during the early years of the program there would not be a consistent match between cost and benefits. This is especially true for the vehicle control portions and initial fuel changes required by the program, where the full vehicle cost would be incurred at the time of vehicle purchase, while the fuel cost along with the emission reductions and benefits resulting from all these costs would occur throughout the lifetime of the vehicle. Because of this inconsistency and our desire to more appropriately match the costs and emission reductions of our program, our analysis uses a future year when the fleet is nearly fully turned over (2030). Consequently, we developed emission inventories through 2030 for both baseline conditions and a control scenario. We present both the benefits as a snapshot in 2030 and as a stream of benefits in the years leading up to 2030. However, our discussion of this analysis focuses on 2030 because the benefits transfer technique applied to these inventories relies on air quality modeling conducted for the year 2030.

10.3.2 Benefits Transfer Methodology

This section summarizes the benefits transfer methodology used in this analysis. This method provides a relatively simple analysis of the health costs of NO_x, and direct PM emissions from Large SI engines. It is important to distinguish these estimates from an analysis that employs full-scale air quality modeling and benefits modeling. The transfer technique used here produces reasonable approximations. Nevertheless, the method also adds uncertainty to the analysis and the results may under or overstate actual benefits of the control program.

Our approach is to develop estimates of health costs expressed in per ton terms. From the Regulatory Model System for Aerosols and Deposition (REMSAD) air quality modeling used for the HD07 rule benefits analysis, we estimated environmental and health costs per ton of NOx and PM. Aggregate environmental and health cost estimates at the national level are scaled to account for human population changes between years of analysis. Complete details of the emissions, air quality, and benefits modeling conducted for the HD07 rule can be found at http://www.epa.gov/otaq/diesel.htm and http://www.epa.gov/ttn/ecas/regdata/tsdhddv8.pdf. Further details of the transfer technique calculations and inputs can be found in the supporting memorandum to the docket (Hubbell 2002a). An alternative approach is presented to provide some insight into the potential of importance of key elements underlying estimates of benefits (Hubbell 2002b).

We examined the impacts of NOx, and direct PM emissions. NOx emissions are associated with both ambient ozone and particulate matter (PM) levels. Due to data limitations, we are providing estimates only for PM related health impacts. The underlying REMSAD modeling partitions the NOx into formation of both ozone and PM in 2030, oxidant chemistry in the model would not lead to over-estimation of secondary PM formation.[4] Note that we do not attempt to quantify ozone-related benefits. Because the vast majority of the benefits we are able to measure and place a monetary value on are PM related, these estimates will capture most of the benefits we are able to monetize associated with the NO_x, and direct PM emission control. However, one important limitation is that benefits from ozone reductions, air toxics reductions, visibility improvement, and other unquantifiable health and welfare endpoints are not captured in these estimates. The results of this original analysis are summarized in Table 10.3-1.

The cost-per-ton estimate presented in Table 10.3-1 is for estimating tons reduced in 2001 based on a U.S. population of 277 million people. To apply this figure to future years, it is necessary to adjust for increases in population (e.g., in 2030, the U.S. population is estimated to be 345 million) and for growth in real income (see Hubbell 2002a and Equation 1 below).

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[4] Additional information about the Regulatory Model System for Aerosols and Deposition (REMSAD) and our modeling protocols can be found in our Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, document EPA420-R-00-026, December 2000. Docket No. A-2000-01, Document No. A-II-13. This document is also available at http://www.epa.gov/otaq/disel.htm#documents. Information can also be found in the docket for the HD07 rulemaking: A-99-06.

Table 10.3-1
Summary of Health Effects and Economic Cost Estimates for Transfer

Health Effect[a]	Incidence/ton in 2001 based on U.S. population of 277 million		Estimated $/ton economic costs in 2001 based on U.S. population of 277 million (1999$)	
	NO_x	PM	NO_x	PM
All-cause Premature Mortality from Long-term Exposure	0.0016	0.0221	$9,726	$136,164
Chronic Bronchitis	0.0010	0.0143	$350	$5,012
Hospital Admissions - COPD	0.0002	0.0024	$2	$30
Hospital Admissions - Pneumonia	0.0002	0.0030	$3	$44
Hospital Admissions - Asthma	0.0002	0.0023	$1	$15
Hospital Admissions - Total Cardiovascular	0.0005	0.0072	$10	$132
Asthma-Related ER Visits	0.0004	0.0053	$0	$2
Asthma Attacks	0.0324	0.4566	$1	$19
Acute Bronchitis	0.0034	0.0479	<$1	$3
Upper Respiratory Symptoms	0.0368	0.5188	$1	$13
Lower Respiratory Symptoms	0.0373	0.5270	$1	$8
Work Loss Days	0.2849	4.0180	$30	$402
Minor Restricted Activity Days (minus asthma attacks)	1.3875	20.9184	$68	$1,023
Totals			$10,193	$142,867

Note that the wide discrepancy between the per ton values of NO_x and direct PM is due to differences in their relative contributions to ambient concentrations of $PM_{2.5}$. The underlying REMSAD modeling partitions NOx between ozone and secondary PM formation.The HD07 analysis examined the impacts in 2030 of reducing SO_2 emissions by 141,000 tons and NO_x emissions by 2,570,000 tons, as well as a 109,000 ton reduction in direct PM emissions.

[a] 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 and reduced lower respiratory symptoms. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies 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 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.

10.3.3 Overview of Heavy Duty Engine/Diesel Fuel Benefits Analysis and Development of Benefits Transfer Technique

This section provides an overview of the original Heavy Duty Engine/Diesel Fuel 2007 rule (HD07) benefits analysis as it relates to the development of a benefits transfer technique.

The HD07 analysis examined the impacts in 2030 of reducing SO_2 emissions by 141,000 tons and NO_x emissions by 2,570,000 tons, as well as a 109,000 ton reduction in direct PM emissions. Table 10.3-2 summarizes the NOx and direct PM results in aggregate and on a per ton basis.

Table 10.3-2
Summary of Results from 2030 HD Engine/Diesel Fuel Health Benefits Analysis

Health Outcome	**NO_x**		**PM**	
	Avoided Incidences		**Avoided Incidences**	
	Total	**Per Ton**	**Total**	**Per Ton**
Premature Mortality				
All-cause premature mortality from long-term exposure	5,027	0.00196	3,007	0.02759
Chronic Illness				
Chronic Bronchitis (pooled estimate)	3,243	0.00126	1,941	0.01781
Hospital Admissions				
COPD	554	0.00022	331	0.00304
Pneumonia	676	0.00026	404	0.00371
Asthma	523	0.00002	313	0.00289
Total Cardiovascular	1,635	0.00064	978	0.00897
Asthma-Related ER Visits	1,209	0.00047	723	0.00663
Other Effects				
Asthma Attacks	103,905	0.04043	62,135	0.57005
Acute Bronchitis	10,874	0.00423	6,515	0.05977
Upper Respiratory Symptoms	118,063	0.04594	70,601	0.64771
Lower Respiratory Symptoms	119,760	0.04660	71,711	0.65790
Work Loss Days	914,055	0.35566	546,744	5.01600
Minor Restricted Activity Days (minus asthma attacks)	4,763,239	1.85300	2,846,434	26.11407

In the original HD07 analyses, we used the air quality model, REMSAD, which is a three-dimensional grid-based Eulerian air quality model designed to estimate annual particulate concentrations and deposition over large spatial scales (e.g., over the contiguous U.S.) as summarized in Chapter 1 above. The HD07 RIA benefits analysis applies the modeling system to the entire U.S. for two future-year scenarios: a 2030 base case and a 2030 HD Engine/Diesel Fuel control scenario. The PM species modeled by REMSAD include a primary fine fraction (corresponding to particulates less than 2.5 microns in diameter) and several secondary particles (e.g., sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondary particles.

For the purposes of this analysis, we separated the predicted 2030 change in the primary and secondarily-formed components of $PM_{2.5}$ (i.e., sulfates and nitrates) to provide attributable health effects for SO_2 and NO_x. We did this by separating these chemically speciated fractions of PM (e.g., particulate elemental carbon, and total organic aerosols, sulfate, and particulate nitrate (PNO_3)). It is reasonable to separate these predicted concentrations because of the limited interactions of secondary sulfate and nitrates within the modeling system and the limited contribution of secondary organic aerosols (SOA) to TOA (i.e., since there little or no change in HCs in the original HD07 scenario). Because the original HD07 modeling did not examine the type of HC reductions that are present in this rulemaking, we are not able to create a transfer technique for the HC that would contribute to PM formation. Thus, we limit our consideration of secondary formation of PM to the NO_x emissions in this analysis.

To develop the NOx transfer values, we estimated the incidences of the health endpoints we are able to quantify using the population weighted change in nitrate of -0.388 micrograms per cubic meter into each of the concentration-response functions used in the HD07 benefits analysis. This yields estimates of the health effects associated with the NO_x emission reductions. Based on 2030 populations, this change leads to the estimated reductions in health effects listed in the second column of Table 10.3-2. Note that for concentration response (C-R) functions that use daily average $PM_{2.5}$ or PM_{10} levels, use of the annual mean as a proxy for daily averages will over or underestimate the annual incidence by a small amount (less than five percent). We then divided the attributable incidences by NO_x tons reduced in the HD07 analysis, resulting in incidences per ton of NO_x reduced in 2030 as listed in the third column of Table 10.3-2. We then scaled the incidences per ton by the ratio of population in the year of analysis to population in 2030 to obtain incidences per ton for each year (Hubbell 2002).

We conducted a similar operation to develop coefficients for direct PM. In this instance, we started with the population-weighted change in primary PM of -0.232 micrograms per cubic meter in the HD07 analysis.

$$Benefits_{YearI} = \sum I_{P,E} \times T_{YearI,\,p} \times RatioPop_{YearI} \times Value_{YearI,\,E} \qquad \textbf{[1]}$$

Where
$Benefits_{YearI}$ = Monetized Benefits in Year *I*, pollutant *P*
$I_{P,E}$ = Avoided Incidence per ton pollutant *P* for endpoint *E*
$T_{year\ I,\ p}$ = Tons pollutant *P* in Year *I*
$RatioPop_{YearI}$ = Population ratio between year of analysis and 2030
$Value_{YearI,\ E}$ = Monetary value per avoided incidence of endpoint *E* in Year *I*

10.3.4. Quantifying and Valuing Individual Health Endpoints

This section summarizes the studies used to calculate the health incidences and valuation of those incidences both in the original HD07 benefits analysis and relied on here. Quantifiable health benefits of the final Large SI/Recreational Vehicle rule may be related to PM only, or both PM and ozone. We are not estimating any ozone-related benefits, so this analysis is only a partial quantification of the benefits associated with the emission controls for these categories. PM-only health effects include premature mortality, chronic bronchitis, acute bronchitis, upper and lower respiratory symptoms, and work loss days.[5] Health effects related to both PM and ozone include hospital admissions, asthma attacks, and minor restricted activity days.

For this analysis, we rely on concentration response (C-R) functions estimated in published epidemiological studies relating serious health effects to ambient air quality. The specific studies from which C-R functions are drawn are included in Table 10.3-3. A complete discussion of the C-R functions used for this analysis and information about each endpoint are contained in the HD07 RIA and supporting documents. It is important to note that although there may be biologically relevant differences between direct PM from diesels and from gasoline engines, the primary health studies on which the HD07 benefits assessment is based relied on ambient measurements of PM, not diesel-specific exposure information. Thus, we avoid an uncertainty of transferring a diesel-PM health estimate to gasoline-PM situation.

While a broad range of serious health effects have been associated with exposure to elevated PM levels (as noted for example in Table 10.2-1 and described more fully in the ozone and PM Criteria Documents (US EPA, 1996a, 1996b), we include only a subset of health effects in this quantified benefit analysis. Health effects are excluded from this analysis for four reasons:

(i) lack of an adequate benefits transfer technique;
(ii) the possibility of double counting (such as hospital admissions for specific respiratory diseases);
(iii) uncertainties in applying effect relationships based on clinical studies to the affected population; and
(iv) a lack of an established C-R relationship.

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[5] Some evidence has been found linking both PM and ozone exposures with premature mortality. The SAB has raised concerns that mortality-related benefits of air pollution reductions may be overstated if separate pollutant-specific estimates, some of which may have been obtained from models excluding the other pollutants, are aggregated. In addition, there may be important interactions between pollutants and their effect on mortality (EPA-SAB-Council-ADV-99-012, 1999; a copy of this document is available in Docket A-99-06, Document IV-A-20). Because of concern about overstating of benefits and because the evidence associating mortality with exposure to PM is currently stronger than for ozone, only the benefits related to the long-term exposure study (ACS/Krewkski, et al, 2000) of mortality are included in the total primary benefits estimate. A copy of Krewski, et al., can be found in Docket A-99-06, Document No. IV-G-75.

Table 10.3-3
Endpoints and Studies Included in the Primary Analysis

Endpoint	**Study**	**Study Population**
Premature Mortality		
Long-term exposure	Krewski, et al. (2000)[A]	Adults, 30 and older
Chronic Illness		
Chronic Bronchitis (pooled estimate)	Abbey, et al. (1995) Schwartz, et al. (1993)	> 26 years > 29 years
Hospital Admissions		
COPD	Samet, et al. (2000)	> 64 years
Pneumonia	Samet, et al. (2000)	> 64 years
Asthma	Sheppard, et al. (1999)	< 65 years
Total Cardiovascular	Samet, et al. (2000)	> 64 years
Asthma-Related ER Visits	Schwartz, et al. (1993)	All ages
Other Illness		
Asthma Attacks	Whittemore and Korn (1980)	Asthmatics, all ages
Acute Bronchitis	Dockery et al. (1996)	Children, 8-12 years
Upper Respiratory Symptoms	Pope et al. (1991)	Asthmatic children, 9-11
Lower Respiratory Symptoms	Schwartz et al. (1994)	Children, 7-14 years
Work Loss Days	Ostro (1987)	Adults, 18-65 years
Minor Restricted Activity Days (minus asthma attacks)	Ostro and Rothschild (1989)	Adults, 18-65 years

[A] Estimate derived from Table 31, PM2.5(DC), All Causes Model (Relative Risk =1.12 for a 24.5 μg/m^3 increase in mean PM$_{2.5}$).

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 methodology used in a number of recent time-series studies of short-term exposures to air pollution and health effects (Greenbaum, 2002). 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 mortality 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, 2002) 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.[6] 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

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

short-term exposure to PM_{10} from The National Morbidity, Mortality and Air Pollution Study (NMMAPS) were overestimated (this study was *not* used in this benefits analysis of fine particle effects).[7] However, both the relative magnitude and the direction of bias introduced by the convergence issue is 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).

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 and 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 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 estimated benefits, 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.

In Table 10.3-4, we present how we have valued the estimated changes in health effects and the value functions selected from the peer reviewed literature to provide monetized estimates. One of the most important effects is premature mortality. While the base value for a mortality incidence is \$6.1 million (1999\$), this number is always adjusted downward to reflect the impact of discounting over the assumed 5 year lag period between reductions in PM concentrations and full realization of reduced mortality. The lag-adjusted base VSL is \$5.8 million (1999\$) when a 3% discount rate is assumed. Thus the attached table reflects income adjustments applied to these lag adjusted base values.

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[7] 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. A copy of this document can be found in Docket A-2000-01, Document IV-A-201.

Table 10.3-4
Unit Values Used for Economic Valuation of Health Endpoints

Health or Welfare Endpoint	Estimated Value per Incidence (1999$) Central Estimate	Derivation of Estimates
Respiratory Ailments Not Requiring Hospitalization		
Premature Mortality	$6 million per statistical life	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).
Chronic Bronchitis (CB)	$331,000	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.
Hospital Admissions		
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	The 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	The 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 pneumonia category illnesses) reported in Elixhauser (1993).
Asthma admissions	$6,634	The 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 asthma category illnesses) reported in Elixhauser (1993).
All Cardiovascular (ICD codes 390-429)	$18,387	The 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 cardiovascular illnesses) reported in Elixhauser (1993).
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	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 additivity of WTPs. The dollar value for URS is the average of the dollar values for the 7 different types of URS.
Lower Respiratory Symptoms (LRS)	$15	Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz, et al.

Acute Bronchitis	$57	Average of low and high values recommended for use in Section 812 analysis (Neumann, et al. 1994)
Restricted Activity and Work Loss Days		
Work Loss Days (WLDs)	Variable	Regionally adjusted median weekly wage for 1990 divided by 5 (adjusted to 1999$) (US Bureau of the Census, 1992).
Minor Restricted Activity Days (MRADs)	$48	Median WTP estimate to avoid one MRAD from Tolley, et al. (1986) .

10.3.5. Estimating Monetized Benefits Anticipated in Each Year

We applied these estimates of the value per incidence to calculate a stream of benefits in future years. We scaled the benefits to the appropriate future year national populations to reflect growth in population. Our projections reflect the U.S. Bureau of the Census predictions.

Our analysis accounts for expected growth in real income over time. Economic theory argues that willingness to pay (WTP) for most goods (such as environmental protection) will increase if real incomes increase. There is substantial empirical evidence that the income elasticity[8] of WTP for health risk reductions is positive, although there is uncertainty about its exact value. Thus, as real income increases the WTP for environmental improvements also increases. While many analyses assume that the income elasticity of WTP is unit elastic (i.e., ten percent higher real income level implies a ten percent higher WTP to reduce risk changes), empirical evidence suggests that income elasticity is substantially less than one and thus relatively inelastic. As real income rises, the WTP value also rises but at a slower rate than real income.

The effects of real income changes on WTP estimates can influence benefit estimates in two different ways: (1) through real income growth between the year a WTP study was conducted and the year for which benefits are estimated, and (2) through differences in income between study populations and the affected populations at a particular time. Empirical evidence of the effect of real income on WTP gathered to date is based on studies examining the former. 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).

Based on a review of the available income elasticity literature, we adjust the valuation of human health benefits upward to account for projected growth in real U.S. income. Faced with a dearth of estimates of income elasticities derived from time-series studies, we applied estimates derived from cross-sectional studies in our analysis. Details of the procedure can be found in Kleckner and Neumann (1999). An abbreviated description of the procedure we used to account

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[8] Income elasticity is a common economic measure equal to the percentage change in WTP for a one percent change in income.

for WTP for real income growth between 1990 and 2030 is presented in the HD07 TSD.

Incidences in future years will have different values based on adjustments to WTP for growth in income over time. (The schedule of adjustment factors and adjusted WTP values to be applied for each year is listed in attachment 2 of the Hubbell 2002, Docket A-2000-01, Document number IV-A-146.) Adjustment factors should not be applied to the values for avoided hospital admissions, as these are cost-of-illness estimates and not WTP estimates. Likewise, adjustment factors should not be applied to the value of work loss days, as this is a wage-based estimate, not WTP.

10.3.6. Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty.[9] This analysis is no exception. As outlined both in this and preceding chapters, there are many inputs used to derive the final estimate of benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological estimates of C-R functions, estimates of values (both from WTP and cost-of-illness studies), population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain, and depending on their location in the benefits analysis, may have a disproportionately large impact on final estimates of total benefits. For example, emissions estimates are a foundation of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small uncertainties in emission levels can lead to much larger impacts on total benefits. A more thorough discussion of uncertainty can be found in the HD07 benefits TSD (Abt Associates, 2000).

Some key sources of uncertainty in each stage of the benefits analysis are:

- Gaps in scientific data and inquiry;
- Uncertainties in the benefit transfer process from the HD07 case to the vehicles covered in this rulemaking;
- Variability in estimated relationships, such as C-R functions, introduced through differences in study design and statistical modeling;
- Errors in measurement and projection for variables such as population growth rates;
- Errors due to misspecification of model structures, including the use of surrogate

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[9] It should be recognized that in addition to uncertainty, the annual benefit estimates for the final Large SI/Recreational Vehicle rule presented in this analysis are also inherently variable, due to the truly random processes that govern pollutant emissions and ambient air quality in a given year. Factors such as weather display constant variability regardless of our ability to accurately measure them. As such, the estimates of annual benefits should be viewed as representative of the types of benefits that will be realized, rather than the actual benefits that would occur every year.

variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions; and
- Biases due to omissions or other research limitations.

Some of the key uncertainties in the benefits analysis are presented in Table 10.3-5. There are a wide variety of sources for uncertainty and the potentially large degree of uncertainty in our estimate. In the original HD07 benefits assessment, sensitivity analyses were performed including qualitative discussions, probabilistic assessments, alternative calculations, and bounding exercises. For some parameters or inputs it may be possible to provide a statistical representation of the underlying uncertainty distribution. For other parameters or inputs, the information necessary to estimate an uncertainty distribution is not available. Even for individual endpoints, there is usually more than one source of uncertainty. This makes it difficult to provide a quantified uncertainty estimate. For example, the C-R function used to estimate avoided premature mortality has an associated standard error which represents the sampling error around the pollution coefficient in the estimated C-R function. It would be possible to report a confidence interval around the estimated incidences of avoided premature mortality based on this standard error. However, this would omit the contribution of air quality changes, baseline population incidences, projected populations exposed, and transferability of the C-R function to diverse locations to uncertainty about premature mortality. Thus, a confidence interval based on the standard error would provide a misleading picture about the overall uncertainty in the estimates. Information on the uncertainty surrounding particular C-R and valuation functions is provided in the HD07 benefits TSD (Abt Associates, 2000). But, this information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

Many benefits categories, while known to exist, do not have enough information available to provide a quantified or monetized estimate. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many of the serious effects listed in Table 10.2-1. The uncertainty regarding these endpoints is such that we could determine neither a primary estimate nor a plausible range of values. The net effect of excluding benefit and disbenefit categories from the estimate of total benefits depends on the relative magnitude of the effects.

Our estimate of total benefits should be viewed as an approximate result because of the sources of uncertainty discussed above (see Table 10.3-5). The total benefits estimate may understate or overstate actual benefits of the rule. In considering the monetized benefits estimates, the reader should remain aware of the many limitations of conducting these analyses mentioned throughout this chapter.

Table 10.3-5
Primary Sources of Uncertainty in the Benefit Analysis

1. Uncertainties Associated With Concentration-Response Functions

-	The value of the PM-coefficient in each C-R function.
-	Application of a single C-R function to pollutant changes and populations in all locations.
-	Similarity of future year C-R relationships to current C-R relationships.
-	Correct functional form of each C-R relationship.
-	Extrapolation of C-R relationships beyond the range of PM concentrations observed in the study.
-	Application of C-R relationships only to those subpopulations matching the original study population.
2. Uncertainties Associated With Original Modeled Ambient PM Concentrations	
-	Responsiveness of the models to changes in precursor emissions resulting from the control policy.
-	Projections of future levels of precursor emissions, especially ammonia and crustal materials.
-	Model chemistry for the formation of ambient nitrate concentrations.
–	Comparison of model predictions of particulate nitrate with observed rural monitored nitrate levels indicates that REMSAD overpredicts nitrate in some parts of the Eastern US and underpredicts nitrate in parts of the Western US.
3. Uncertainties Associated with PM Mortality Risk	
-	No scientific literature supporting a direct biological mechanism for observed epidemiological evidence.
–	Direct causal agents within the complex mixture of PM have not been identified.
- the year	The extent to which adverse health effects are associated with low level exposures that occur many times in versus peak exposures.
–	The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study.
-	Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated With Possible Lagged Effects	
- levels	The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM would occur in a single year is uncertain as well as the portion that might occur in subsequent years.
5. Uncertainties Associated With Baseline Incidence Rates	
–	Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates.
-	Current baseline incidence rates may not approximate well baseline incidence rates in 2030.
–	Projected population and demographics may not represent well future-year population and demographics.
6. Uncertainties Associated With Economic Valuation	
- have	Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore uncertainty surrounding them.
–	Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income or other factors.
7. Uncertainties Associated With Aggregation of Monetized Benefits	
–	Health and welfare benefits estimates are limited to the available C-R functions. Thus, unquantified or unmonetized benefits are not included.
8. Uncertainties introduced by Transferring Benefits from a Previous Mobile Source Benefits Analysis	
–	The reasonableness of the benefits transfer depends on the similarity of the original analysis and the emission reductions analyzed with respect to the relationship between emissions and human populations.

10.3.7. Estimated Reductions in Incidences of Health Endpoints and Associated Monetary Values

Applying the techniques (including the C-R and valuation functions described above) to the estimated changes in NOx and direct PM emissions yields estimates of the number of avoided incidences (i.e. premature mortalities, cases, admissions, etc.) and the associated monetary values for those avoided incidences. These estimates are presented in Table 10.3-6 for 2030. All of the monetary benefits are in constant 2002 dollars.

Not all known PM- and ozone-related health effects could be quantified or monetized. These unmonetized benefits are indicated by place holders, labeled B_1 and B_2. In addition, unmonetized benefits associated with ozone, CO and HC reductions are indicated by the placeholders $B_{2,}$ $B_{3,}$ and B_4. Unquantified physical effects are indicated by U_1 through U_4. The estimate of total monetized health benefits is thus equal to the subset of monetized PM-related health benefits plus $\mathbf{B_H}$, the sum of the unmonetized health benefits.

The largest monetized health benefit is associated with reductions in the risk of premature mortality, which accounts for over $7.5 billion, which is over 95 percent of total monetized health benefits.[10] The next largest benefit is for chronic bronchitis reductions, although this value is more than an order of magnitude lower than for premature mortality. Minor restricted activity days, work loss days, and worker productivity account for the majority of the remaining benefits. The remaining categories account for less than $10 million each; however, they represent a large number of avoided incidences affecting many individuals.

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[10] Alternative calculations for premature mortality incidences and valuation are presented in the HD07 RIA in Tables VII-24 and VII-25, respectively. An alternative calculation is also provided in Table VII-25 for chronic bronchitis incidences and for chronic asthma incidences. The HD07 RIA can be found in Docket A-2000-01, Document II-A-13.

Table 10.3-6
Base-Case Estimate of Annual Health Benefits Associated With Air Quality Changes Resulting from the Large SI Requirements Only in 2030

Endpoint	**Avoided Incidence[A] (cases/year)**	**Monetary Benefits[B] (millions 2002$, adjusted for growth in real income)**
PM-related Endpoints[C]		
Premature mortality[D] (adults, 30 and over)	1,000	$7,510
Chronic bronchitis (adults, 26 and over)	640	$280
Hospital Admissions – Pneumonia (adults, over 64)	100	<$5
Hospital Admissions – COPD (adults, 64 and over)	100	<$5
Hospital Admissions – Asthma (65 and younger)	100	<$1
Hospital Admissions – Cardiovascular (adults, over 64)	300	<$10
Emergency Room Visits for Asthma (65 and younger)	300	<$1
Asthma Attacks (asthmatics, all ages)[E]	20,600	<$1
Acute bronchitis (children, 8-12)	2,200	<$1
Lower respiratory symptoms (children, 7-14)	23,700	<$1
Upper respiratory symptoms (asthmatic children, 9-11)	23,400	<$1
Work loss days (adults, 18-65)	181,300	$20
Minor restricted activity days (adults, age 18-65)	944,400	$50
Other PM-related health effects[E]	U_1	B_1
Ozone-related Endpoints	U_2	B_2
CO and HC-related health effects[E]	U_3+U_4	B_3+B_4
Monetized Total Health-related Benefits[G]	—	\$7,880+$\mathbf{B}_H$

[A] Incidences are rounded to the nearest 100.

[B] Dollar values are rounded to the nearest $10 million.

[C] PM-related benefits are based on the assumption that Eastern U.S. nitrate reductions are equal to one-fifth the nitrate reductions predicted by REMSAD (see HD07 RIA Chapter II for a discussion of REMSAD and model performance).

[D] Premature mortality associated with ozone is not separately included in this analysis (also note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure). Further, PM-related reductions are not quantified for ATVs, OHMs, snowmobiles and recreational marine diesel.

[E] A detailed listing of unquantified PM, ozone, CO, and HC related health effects is provided in Table 10.2-1.

[F] Based upon recent preliminary findings by the Health Effects Institute, the concentration-response functions used to estimate reductions in hospital admissions may over- or under-estimate the true concentration-response relationship. 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 and reduced lower respiratory symptoms. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies 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 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.

[G] $\mathbf{B}_H$ is equal to the sum of all unmonetized categories, i.e. $B_a+B_1+B_2+B_3+B_4$.

In Table 10.3-7, we present the benefits over time as the regulations phase in over time and a net present value, assuming a 3 percent social discount rate.

Table 10.3-7
Monetized Benefits for Large SI Category Only [A]

Year	Nox Reductions (tons)	PM Reductions (tons)	Total Large SI Benefits (thousands $)
2004	40117	0	$ 420,000
2005	74541	0	$ 800,000
2006	108754	0	$ 1,180,000
2007	152431	0	$ 1,670,000
2008	193218	0	$ 2,150,000
2009	233094	0	$ 2,630,000
2010	271554	0	$ 3,110,000
2011	306016	0	$ 3,820,000
2012	328022	0	$ 4,160,000
2013	347920	0	$ 4,480,000
2014	365688	0	$ 4,790,000
2015	378511	0	$ 5,030,000
2016	389820	0	$ 5,270,000
2017	400470	0	$ 5,490,000
2018	410477	0	$ 5,710,000
2019	419931	0	$ 5,900,000
2020	428805	0	$ 6,130,000
2021	437527	-1	$ 6,320,000
2022	446085	-1	$ 6,540,000
2023	454549	-1	$ 6,750,000
2024	462994	-1	$ 6,950,000
2025	471382	-1	$ 7,120,000
2026	479206	-1	$ 7,280,000
2027	486998	-1	$ 7,440,000
2028	494665	-1	$ 7,600,000
2029	502188	-1	$ 7,740,000
2030	509684	-1	$ 7,880,000
Net Present Value 2002 - 2030			$ 77,180,000

[A] This analysis excludes the health effects we are not able to quantify for PM, ozone, CO, and HC. A detailed list is provided in Table 10.2-1. Only NOx and PM reductions from Large SI are quantified. The sizable PM and Nox reductions from ATVs, OHMs, snowmobiles, and recreational marine diesel are not quantified.

[B] Dollar values are rounded to the nearest $10 million.

[c] A social discount rate of 3 percent is used to calculate the net present value. If a discount rate of 7 percent is used, the net present value (2002 - 2030) is $40.07 billion.

10.3.8 Alternative Calculations of Estimated Reductions in Incidences of Health Endpoints and Associated Monetary Values

We have also evaluated an alternative, more conservative estimate, that can provide useful insight into the potential impacts of the key elements underlying estimates of the benefits of reducing NOx, and PM emissions from this rule through calculated alternative benefits for mortality and chronic bronchitis. The alternative estimate of mortality reduction relies on certain recent available scientific studies. These studies found an association between increased mortality and short-term exposure to PM over days to weeks. The alternative approach uses different data on valuation and makes adjustments relating to the health status and potential longevity of the populations most likely affected by PM (for more details see Hubbell 2002b). We are continuing to examine the merits of applying this alternative approach to the calculation of benefits. Some of the issues that warrant further investigation are described below.

10.3.9 Alternative Calculations of PM Mortality Risk Estimates and Associated Monetary Values

The Alternative Estimate addresses uncertainty 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.[11]

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 from heavy duty vehicles 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

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[11] It is of note that, based on recent preliminary findings from the Health Effects Institute (http://www.healtheffects.org), the magnitude of mortality from short-tern exposure may be under or overestimated.

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. 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).

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. EPA's Science Advisory Board, while acknowledging the uncertainties in estimation of a PM-mortality relationship, has recommended the use of a study that does reflect the impacts of long-term exposure. The omission of long-term impacts accounts for an approximately 40 percent reduction in the estimate of avoided premature mortality in the alternative estimates relative to the primary estimates.

Furthermore, the alternative estimates reflect 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 estimates address 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.

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.

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.

The third issue is addressed in the Alternative Estimate 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. COPD deaths for populations aged 65 and older are valued at $0.13 million per incidence. Finally, COPD deaths for populations aged 64 and younger are valued at $0.09 million per incidence. 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. As a final step, these estimated VSL values are multiplied by the appropriate adjustment factors to account for changes in WTP over time.

10.3.9.1 Alternative Calulations of Chronic Bronchitis Monetary Values

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 primary 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 estimates rely 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. Because the alternative estimate is based on cost-of-illness, no income adjustments are applied when applying the estimate in future year analyses.

10.3.9.2 Alternative Calulations Results

Applying the techniques (including the C-R and valuation alternatives described above) to the estimated changes in NOx and direct PM emissions for Large SI engines from this rule yields estimates of the number of avoided incidences of premature mortalities and chronic bronchitis cases and the associated monetary values for those avoided incidences. These estimates are presented in Table 10.3-8 for 2030. All of the monetary benefits are in constant 2002 dollars.

Table 10.3-8.
Alternative Benefits in 2030 from PM-related Reductions from the Large SI Categories.

	Alternative Estimate Incidence[A]	Alternative Estimation Valuation[B] (million $)
Short-term exposure mortality	600	$810
Chronic bronchitis	640	$90

[A] Incidences are rounded to the nearest 10.
[B] Dollar values are rounded to the nearest $10 million.

In Table 10.3-9, we present the benefits over time as the regulations phase in over time and a net present value, assuming a 3 percent social discount rate.

Table 10.3-9
Alternative Monetized Benefits Mortality and Chronic Bronchitis for Large SI Category Only[A]

Year	Nox Reductions	PM Reductions	Total Benefits (thousands)
2004	40,117	0	$ 50,000
2005	74,541	0	$ 90,000
2006	108,754	0	$ 130,000
2007	152,431	0	$ 190,000
2008	193,218	0	$ 250,000
2009	233,094	0	$ 300,000
2010	271,554	0	$ 350,000
2011	306,016	0	$ 440,000
2012	328,022	0	$ 470,000
2013	347,920	0	$ 510,000
2014	365,688	0	$ 550,000
2015	378,511	0	$ 570,000
2016	389,820	0	$ 600,000
2017	400,470	0	$ 620,000
2018	410,477	0	$ 650,000
2019	419,931	0	$ 670,000
2020	428,805	0	$ 700,000
2021	437,527	-1	$ 720,000
2022	446,085	-1	$ 750,000
2023	454,549	-1	$ 770,000
2024	462,994	-1	$ 790,000
2025	471,382	-1	$ 810,000
2026	479,206	-1	$ 830,000
2027	486,998	-1	$ 850,000
2028	494,665	-1	$ 870,000
2029	502,188	-1	$ 880,000
2030	509,684	-1	$ 900,000
Net Present Value 2002 to 2030			$8,800 million

[A] This alternative analysis excludes the health effects we are not able to quantify for PM, ozone, CO, and HC as well as excluding benefits from long-term exposure mortality, hospital admissions, emergency department visits, upper and lower respiratory symptoms, asthma attacks, acute bronchitis, work loss days and minor restricted activity days. A detailed list is provided in Table 10.2-1. Only NOx and PM reductions from Large SI are quantified. The sizable PM and Nox reductions from ATVs, OHMs, snowmobiles, and recreational marine diesel are not quantified.

[B] Dollar values are rounded to the nearest $10 million.

[c] A social discount rate of 3 percent is used to calculate the net present value. If a discount rate of 7 percent is used, the net present value (2002 - 2030) is $4.57 billion.

10.4 CO and Air Toxics Health Benefits Estimation

Although we achieve substantial reductions in CO and HC (many of which are hazardous air pollutants), we are unable to quantify benefits for these reductions. We present two techniques for estimating the economic benefits of changes in emissions from snowmobiles that are possible areas for further reserach.

10.4.1 Direct Valuation of "Clean" Snowmobiles

In general, economists tend to view an individual's willingness-to-pay (WTP) for a improvement in environmental quality as the appropriate measure of the value of a risk reduction. An individual's willingness-to-accept (WTA) compensation for not receiving the improvement is also a valid measure. However, WTP is generally considered to be a more readily available 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.

For many goods, WTP can be observed by examining actual market transactions. For example, if a gallon of bottled drinking water sells for one dollar, it can be observed that at least some persons are willing to pay one dollar for such water. For goods not exchanged in the market, such as most environmental "goods," valuation is not as straightforward. Nevertheless, a value may be inferred from observed behavior, such as sales and prices of products that result in similar effects or risk reductions, (e.g., non-toxic cleaners or safety devices). Alternatively, surveys may be used in an attempt to directly elicit WTP for an environmental improvement.

One distinction in environmental benefits estimation is between use values and non-use values. Although no general agreement exists among economists on a precise distinction between the two (see Freeman, 1993), the general nature of the difference is clear. Use values are those aspects of environmental quality that affect an individual's welfare more or less directly. These effects include changes in product prices, quality, and availability, changes in the quality of outdoor recreation and outdoor aesthetics, changes in health or life expectancy, and the costs of actions taken to avoid negative effects of environmental quality changes.

Non-use values are those for which an individual is willing to pay for reasons that do not relate to the direct use or enjoyment of any environmental benefit, but might relate to existence values and bequest values. Non-use values are not traded, directly or indirectly, in markets. For this reason, the measurement of non-use values has proved to be significantly more difficult than the measurement of use values. The air quality changes produced by the final Large SI/Recreational Vehicle rule cause changes in both use and non-use values, but the monetary benefit estimates are almost exclusively for use values.

The most direct way to measure the economic value of air quality changes is in cases where the endpoints have market prices. More frequently than not, the economic benefits from environmental quality changes are not traded in markets, so direct measurement techniques can not be used.

Estimating benefits for public land activities or its existence value is a more difficult and less precise exercise because the endpoints are not directly or indirectly valued in markets. For example, the loss of a species of animal or plant from a particular habitat does not have a well-defined price, neither does a crisp winter day of quietude. The contingent valuation (CV) method has been employed in the economics literature to value endpoint changes for both visibility and ecosystem functions (Chestnut and Dennis, 1997). There is an extensive scientific literature and body of practice on both the theory and technique of CV. EPA believes that well-designed and well-executed CV studies are valid for estimating the benefits of air quality regulation.[12]

The contingent valuation (CV) method uses survey techniques to estimate values individuals place on goods and services for which no market exists. Contingent valuation has been widely applied (Mitchell and Carson 1989, and Walsh, Johnson, and McKean 1992), and the U.S. Water Resources Council recognizes this as an appropriate method. The U.S. Department of Interior's federal guidelines have designated CV as the best available procedure for valuing damages arising in Superfund natural resource damage cases (U.S. DOI 1986, 1991).

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. In a CV survey, individuals are asked about their willingness to pay for a given service or commodity contingent on their acceptance of a hypothetical but plausible and realistic market situation. Thus, there are three main elements in the approach: 1) a description of the commodity to be valued; 2) the payment vehicle (i.e., how the individual will pay for the good or service); and 3) the form of the question (e.g., open-ended or dichotomous choice questions). A study that contained information about use value for "clean, quiet" snowmobiles was recently conducted (Duffield and Neher 2000).[13] However, the study was judged to have limitations in its application here. The National Park Service is endeavoring to conduct a new study that may address the short-comings of this study.

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[12] 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.

[13] Duffield, JW and CJ Neher. Winter 1998-99 Visitor Survey: Yellowstone National Park, Grand Teton National Park, and Greater Yellowstone Area. May 2000. Docket A-2000-01, Document IV-A-113. The survey instrument and the report were independently peer-reviewed.

10.4.2 Overview of Benefits Estimation for CO and Air Toxics from the Final Rule

A large variety of substances is emitted from tail pipes of snowmobiles powered by two-stroke engines.[1] Some of these substances may be acutely neurotoxic at sufficiently high concentration, including volatile hydrocarbons (HC) and carbon monoxide (CO). The acute neurotoxicity of only two of the identified exhaust components have been studied extensively on an individual basis (toluene and CO), but the combined toxicity of the mixture of toluene and CO has not been evaluated.[2] Toluene comprises about 20 percent of the total amount of hydrocarbons in the exhaust of snowmobiles.[3] As discussed above, up to a third of the fuel and lubricating oil mixture delivered to the 2-stroke snowmobile engine is emitted directly without being burned.

Ideally, we would have quantified the economic benefit of reductions in all of these pollutants from vehicles subject to our final rule. In developing a method to quantify economic benefits for the reduction of these toxic pollutants, however, we were limited by the available exposure literature to modeling a specific common exposure scenario for snowmobiles. After detailed subsequent investigation of the limited exposure information, we judge the study to contain too many unresolved uncertainties to be used in this analysis. Further, we are not able to quantify exposures related to other high-emitting 2-stroke engines in ATVs or OHMCs. Furthermore, there are substantial uncertainties in the analysis and gaps in our underlying knowledge. More research is needed, especially regarding exposure to neurotoxicants emitted from these and other categories of 2-stroke engines to facilitate benefits calculations.

If after further study, we learn that off-road vehicle operators are exposed to combined levels of neurotoxicants at levels that impair skills related to driving ability,[4] then reductions in these exposures could result in fewer accidents and avoided medical and property damage costs. However, we were limited by gaps in knowledge about exposure estimates and health effects related to most neurotoxic compounds. For air toxics and CO, it can be important to consider both momentary blood dose as well as longer term exposures in evaluating the health effects and monetary benefits.

10.5 Total Benefits

We provide our base-case estimate of benefits for each health and welfare endpoint as well as the resulting base-case estimate of total benefits. To obtain this estimate, we aggregate dollar benefits associated with each of the effects examined, such as hospital admissions, into a total benefits estimate assuming that none of the included health and welfare effects overlap. The base-case estimate of the total benefits associated with the health and welfare effects is the sum of the separate effects estimates. Total monetized benefits associated with the final Large SI/Recreational Vehicle rule are listed in Table 10.5-1, along with a breakdown of benefits for the Large SI category only by endpoint. Note that the value of endpoints known to be affected by ozone and/or PM that we are not able to monetize are assigned a placeholder value (e.g., B_1, B_2, etc.). Unquantified physical effects are indicated by a U. The estimate of total benefits is thus the sum of the monetized benefits and a constant, B, equal to the sum of the unmonetized benefits, $B_1+B_2+...+B_n$.

A comparison of the incidence column to the monetary benefits column reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there many times more asthma attacks than premature mortalities, yet these asthma attacks account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as asthma attacks, are valued using a proxy measure of WTP. As such the true value of these effects may be higher than that reported in Table 10.5-1.

Table 10.5-1
Base-Case Estimate of Annual Health Benefits Associated With Air Quality Changes Resulting from the Large SI/Recreational Vehicle Rule in 2030

Endpoint	Avoided Incidence[A] (cases/year)	Monetary Benefits[B] (millions 2002$, adjusted for growth in real income)
PM-related Endpoints[C]		
Premature mortality[D] (adults, 30 and over)	1,000	$7,510
Chronic bronchitis (adults, 26 and over)	640	$280
Hospital Admissions – Pneumonia (adults, over 64)[F]	100	<$5
Hospital Admissions – COPD (adults, 64 and over)	100	<$5
Hospital Admissions – Asthma (65 and younger)	100	<$1
Hospital Admissions – Cardiovascular (adults, over 64)	300	<$10
Emergency Room Visits for Asthma (65 and younger)	300	<$1
Asthma Attacks (asthmatics, all ages)[E]	20,600	<$1
Acute bronchitis (children, 8-12)	2,200	<$1
Lower respiratory symptoms (children, 7-14)	23,700	<$1
Upper respiratory symptoms (asthmatic children, 9-11)	23,400	<$1
Work loss days (adults, 18-65)	181,300	$20
Minor restricted activity days (adults, age 18-65)	944,400	$50
Other PM-related health effects[E]	U_1	B_1
Ozone-related Endpoints	U_2	B_2
Quantified HC-related WTP	--	U_3
CO and HC-related health effects[E]	U_4+U_5	B_3
Monetized Total Health-related Benefits[G]	—	$7,880 + $\mathbf{B_H}$

[A] Incidences are rounded to the nearest 100. Nox and PM-related reductions are not quantified for ATVs, OHMs, snowmobiles and recreational marine diesel.

[B] Dollar values are rounded to the nearest $10 million.

[C] PM-related benefits are based on the assumption that Eastern U.S. nitrate reductions are equal to one-fifth the nitrate reductions predicted by REMSAD (see HD07 RIA Chapter II for a discussion of REMSAD and model performance).

[D] Premature mortality associated with ozone is not separately included in this analysis (also note that the estimated value for PM-related premature mortality assumes the 5 year distributed lag structure).

[E] A detailed listing of unquantified PM, ozone, CO, and HC related health effects is provided in Table 10.2-1.

[F] Based upon recent preliminary findings by the Health Effects Institute, the concentration-response functions used to estimate reductions in hospital admissions may over- or under-estimate the true concentration-response relationship. 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 and reduced lower respiratory symptoms. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies 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 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.

[G] $\mathbf{B_H}$ is equal to the sum of all unmonetized categories, i.e. B_a+B_1

10.6 Comparison of Costs to Benefits

Benefit-cost analysis provides a valuable framework for organizing and evaluating information on the effects of environmental programs. When used properly, benefit-cost analysis helps illuminate important potential effects of alternative policies and helps set priorities for closing information gaps and reducing uncertainty. According to economic theory, the efficient policy alternative maximizes net benefits to society (i.e., social benefits minus social costs). However, not all relevant costs and benefits can be captured in any analysis. Executive Order 12866 clearly indicates that unquantifiable or nonmonetizable categories of both costs and benefits should not be ignored. There are many important unquantified and unmonetized costs and benefits associated with reductions in emissions, including many health and welfare effects. Potential benefit categories that have not been quantified and monetized are listed in Table 10.2-1 of this chapter.

The estimated social cost (measured as changes in consumer and producer surplus) in 2030 to implement the final Large SI/Recreational Vehicle program from Chapter 9 is $216 million (2001$). The net social gain, considering fuel efficiency, is $553 million. The monetized benefits are approximately $7.8 billion, and EPA believes there is considerable value to the public of the benefits it could not monetize. The net benefit that can be monetized is $8.4 billion. Therefore, implementation of the Large SI/Recreational Vehicle program is expected to provide society with a net gain in social welfare based on economic efficiency criteria. Table 10.6-1 summarizes the costs, benefits, and net benefits.

Table 10.6-1

	Millions of 2001$[a]
Social Gains	$550
Monetized PM-related benefits[b,c]	$7,880 + $\mathbf{B_{PM}}$
Monetized Ozone-related benefits[b,d]	not monetized ($\mathbf{B_{Ozone}}$)
HC-related benefits	not monetized ($\mathbf{B_{HC}}$)
CO-related benefits	not monetized ($\mathbf{B_{CO}}$)
Total annual benefits	$7,880 +$\mathbf{B_{PM}}$ + $\mathbf{B_{Ozone}}$ + $\mathbf{B_{HC}}$ + $\mathbf{B_{CO}}$
Monetized net benefits[e]	$8,430 + **B**

[a] For this section, all costs and benefits are rounded to the nearest 10 million. Thus, figures presented in this chapter may not exactly equal benefit and cost numbers presented in earlier sections of the chapter.
[b] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table IX-E.2**.** Unmonetized PM- and ozone-related benefits are indicated by B_{PM}. And B_{Ozone}, respectively.
[c] Based upon recent preliminary findings by the Health Effects Institute, the concentration-response functions used to estimate reductions in hospital admissions may over- or under-estimate the true concentration-response relationship.
[d] There are substantial uncertainties associated with the benefit estimates presented here, as compared to other EPA analyses that are supported by specific modeling. This analysis used a benefits transfer technique described in the RSD.
[e] **B** is equal to the sum of all unmonetized benefits, including those associated with PM, ozone, CO, and HC.

The net present value of the future benefits has also been calculated, using a 3 percent discount rate over the 2002 to 2030 time frame. The net present value of the social gains, from Table 9.1-7 of Chapter 9, is $4,930 million. The net present value of the total annual benefits, from Tables 10.3-7 and 10.4-3, is $77,177 million + B. Consequently, the net present value of the monetized net benefits of this program is $82,107 million.

For each of the vehicle categories, the net present value of the future streams of surplus losses, fuel savings, social costs/gains, health and environmental benefits and net cost/benefits have been calculated. The net present values of these future streams are calculated using a 3 percent discount rate (in Chapters 9, 10, and 11) and are calculated over the 2002 to 2030 time frame.

These net present value estimates are sensitive to the discount rate. Table 10.6-2 presents an alternative net present value calculation of the surplus loss, fuel savings, social costs/gains, health and environmental benefits, and net cost or benefits for the control programs being adopted in this rulemaking, for each vehicle category, for the period 2002 to 2030, assuming an alternative discount rate of 7%.

Table 10.6-2
Net Present Values*, Fuel Cost Savings, and Social Costs/Gains (millions of 2001$)**

Vehicle Category	NPV of Surplus Loss	NPV of Fuel Cost Savings	NPV of Social Costs/Gains ***
CI Marine	$59.0	$0.0	$59.0
Forklifts	$415.8	$2,644.2	($2,228.4)
Other Large SI****	$419.7	$804.8	($385.1)
Snowmobiles	$296.9	$459.7	($162.8)
ATVs	$491.9	$253.0	$238.9
Off-Highway Motorcycles	$206.2	$120.6	$85.6
Total	**$1,889.5**	**$4,282.3**	**($2,392.8)**

* Net Present Values are calculated using a discount rate of 7 percent over the 2002 - 2030 time period.

** Figures are in year 2000 and 2001 dollars, depending on the vehicle category; ( ) represents a negative cost (social gain).

***Figures in this column exclude estimated health and environmental benefits.

****Figures in this row are engineering cost estimates. See Section 9.7.6 of Chapter 9.

The net present value of the future benefits has also been calculated, using a 7 percent discount rate over the 2002 to 2030 time frame. The net present value of the social gains from above, is $2,393 million. The net present value of the total annual health and environmental benefits that we were able to quantify using a 7 percent discount rate is $40,070 million + B. Consequently, the net present value of the monetized net benefits of this program using a 7 percent discount rate is $42,477 + B million.

Chapter 10 Bibliography

Abbey, D.E., B.L. Hwang, R.J. Burchette, T. Vancuren, and P.K. Mills. 1995a. "Estimated Long-Term Ambient Concentrations of PM(10) and Development of Respiratory Symptoms in a Nonsmoking Population." *Archives of Environmental Health* 50(2): 139-152.

Abbey, D.E., F. Petersen, P. K. Mills, and W. L. Beeson. 1993. "Long-Term Ambient Concentrations of Total Suspended Particulates, Ozone, and Sulfur Dioxide and Respiratory Symptoms in a Nonsmoking Population." *Archives of Environmental Health* 48(1): 33-46.

Abt Associates Inc., 2000.. *Heavy Duty Engine/Diesel Fuel Rule: Air Quality Estimation, Selected Health and Welfare Benefits Methods, and Benefit Analysis Results*. Prepared for US EPA, Office of Air Quality Planning and Standards. Research Triangle Park, NC. November. A copy of this document can be found in Docket A-2000-01, Document IV-A-219.

Abt Associates, Inc., 1999a. *Tier2 Final Rule: Air Quality Estimation, Selected Health and Welfare Benefits Methods, and Benefit Analysis Results,* Prepared for the US Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, November.

Abt Associates Inc., 1999b. Memorandum to Lisa Conner, US EPA, Office of Air Quality Planning and Standards. "Derivation of 2030 Population Estimates for the Tier II Analysis." September.

Abt Associates Inc., 1998. *Air Quality Estimation for the NOx SIP Call RIA*. Prepared for US EPA, Office of Air Quality Planning and Standards, under contract no. 68-D-98-001. Research Triangle Park, NC. September. See EPA Air Docket A-96-56, Document No. VI-B-09.

American Lung Association, 1999. Chronic Bronchitis. Web site available at: http://www.lungusa.org/diseases/lungchronic.html.

Blumenschein, K. and M. Johannesson. 1998. "Relationship Between Quality of Life Instruments, Health State Utilities, and Willingness to Pay in Patients with Asthma." *Annals of Allergy, Asthma, and Immunology* 80:189-194.

Benignus, V, W Boyes, and P. Bushnell, US Environmental Protection Agency. National Health and Environmental Effects Research Laboratory. Memorandum to the Docket. Acute Behavioral Effects of Exposure to Toluene and Carbon Monoxide from Snowmobile Exhaust. September 2002. A copy of this document can be found in Docket A-2000-01, Document IV-A-143.

Chestnut, L.G. 1997. Draft Memorandum: *Methodology for Estimating Values for Changes in Visibility at National Parks.* April 15.

Chestnut, L.G. and R.L. Dennis. 1997. Economic Benefits of Improvements in Visibility: Acid

Rain Provisions of the 1990 Clean Air Act Amendments. *Journal of Air and Waste Management Association* 47:395-402.

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

Chestnut, L.G. and R.D. Rowe. 1990a. *Preservation Values for Visibility Protection at the National Parks: Draft Final Report.* Prepared for Office of Air Quality Planning and Standards, US Environmental Protection Agency, Research Triangle Park, NC and Air Quality Management Division, National Park Service, Denver, CO.

Crocker T. D. and R. L. Horst, Jr. 1981. "Hours of Work, Labor Productivity, and Environmental Conditions: a Case Study." *The Review of Economics and Statistics* 63:361-368.

Delfino, R.J., R.S. Zeiger, J.M. Seltzer, and D.H. Street. 1998. Symptoms in Pediatric Asthmatics and Air Pollution: Differences in Effects by Symptom Severity, Anti-inflammatory Medication Use and Particulate Averaging Time. *Environmental Health Perspectives*, 106(11): 751-761.

Delfino, R.J., R.S. Zeiger, J.M. Seltzer, and D.H. Street, 1998. Symptoms in Pediatric Asthmatics and Air Pollution: Differences in Effects by Symptom Severity. Anti-inflammatory Medication Use and Particulate Averaging Time. *Environmental Health Perspectives*, 106(11): 751-761.

Dennis, R.L., 1997. "Using the Regional Acid Deposition Model to Determine the Nitrogen Deposition Airshed of the Chesapeake Bay Watershed." In: *Atmospheric Deposition to the Great Lakes and Coastal Waters*. Baker, J.E., ed. Society of Environmental Toxicology and Chemistry, Pensacola, FL. pp. 393-413. See EPA Air Docket A-96-56, Document No. VI-B-09.

Desvousges, W.H., F. R. Johnson, and H.S. Banzhaf. 1998. *Environmental Policy Analysis with Limited Information: Principles and Applications of the Transfer Method*. Edward Elgar, Northhampton, MA.

Dickie, M. et al. 1991. Reconciling Averting Behavior and Contingent Valuation Benefit Estimates of Reducing Symptoms of Ozone Exposure (draft), as cited in Neumann, J.E., Dickie, M.T., and R.E. Unsworth. 1994. Industrial Economics, Incorporated. Memorandum to Jim DeMocker, US EPA, Office of Air and Radiation. March 31.

Dillman, D. 1992. Mail and Telephone Surveys. John Wiley Publishing. New York.

Dockery, D.W., C.A. Pope, X.P. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, B.G. Ferris and F.E. Speizer. 1993. "An association between air pollution and mortality in six U.S. cities." *New England Journal of Medicine* 329(24): 1753-1759.

Dockery, D.W., J. Cunningham, A.I. Damokosh, L.M. Neas, J.D. Spengler, P. Koutrakis, J.H. Ware, M. Raizenne and F.E. Speizer. 1996. “Health Effects of Acid Aerosols On North American Children-Respiratory Symptoms.” *Environmental Health Perspectives*. 104(5): 500-505.

Douglas, S.G. and R.K. Iwamiya, 1999. *Estimating the Effects of the Tier 2 Motor-Vehicle Standards on Air Quality: Ozone*. Prepared for Abt Associates, Inc. Prepared by Systems Applications International, Inc. SYSAPP-99-98/50. January.

Duffield, J.W., Neher, C. J. Winter 1998-99 Visitor Survey Yellowstone N.P., Grand Teton N.P., and the Greater Yellowstone Area Final Report. Report prepared for National Park Service, Denver, CO. May, 2000. This document is available in Docket A-2000-01, Document IV-A-114.

E.H. Pechan & Associates, 1996. R*egional Particulate Control Strategies Phase II*. Prepared for the US Environmental Protection Agency, Office of Policy, Planning, and Evaluation. Washington, DC. September.

E.H. Pechan & Associates, 1999. *Emissions and Air Quality Impacts of Proposed Motor Vehicle Tier 2 and Fuel Sulfur Standards*. Prepared by The Pechan-Avanti Group under EPA Contract No. 68-D9-8052. for US EPA, Office of Air Quality Planning and Standards, Innovative Strategies and Economics Group. Research Triangle Park, NC. January.

Elixhauser, A., R.M. Andrews, and S. Fox. 1993. Clinical Classifications for Health Policy Research: Discharge Statistics by Principal Diagnosis and Procedure. Agency for Health Care Policy and Research (AHCPR), Center for General Health Services Intramural Research, US Department of Health and Human Services.

Empire State Electric Energy Research Corporation (ESEERCO). 1994. *New York State Environmental Externalities Cost Study. Report 2: Methodology*. Prepared by: RCG/Hagler, Bailly, Inc., November.

EPA-SAB, Health and Ecological Effects Subcommittee of the Advisory Council on Clean Air Act Compliance Analysis. 1999. Summary Minutes of Public Meeting, April 21-22, 1999.

EPA-SAB-COUNCIL-ADV-99-05, 1999. An SAB Advisory on the Health and Ecological Effects Initial Studies of the Section 812 Prospective Study: Report to Congress: Advisory by the Health and Ecological Effects Subcommittee, February.

EPA-SAB-COUNCIL-ADV-98-003, 1998. Advisory Council on Clean Air Compliance Analysis Advisory on the Clean Air Act Amendments (CAAA) of 1990 Section 812 Prospective Study: Overview of Air Quality and Emissions Estimates: Modeling, Health and Ecological Valuation Issues Initial Studies.

EPA-SAB-COUNCIL-ADV-99-012, 1999. The Clean Air Act Amendments (CAAA) Section

812 Prospective Study of Costs and Benefits (1999): Advisory by the Health and Ecological Effects Subcommittee on Initial Assessments of Health and Ecological Effects: Part 1. July. A copy of this document can be found in Docket A-2000-01, Document IV-A-204.

EPA-SAB-COUNCIL-ADV-00-001, 1999. The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Health and Ecological Effects Subcommittee on Initial Assessments of Health and Ecological Effects: Part 2. October, 1999.

EPA-SAB-COUNCIL-ADV-00-002, 1999. The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Advisory Council on Clean Air Compliance Analysis: Costs and Benefits of the CAAA. Effects Subcommittee on Initial Assessments of Health and Ecological Effects: Part 2. October, 1999.

EPA-SAB-EEAC-00-013, 2000. An SAB Report on EPA's White Paper *Valuing the Benefits of Fatal Cancer Risk Reduction*.US Environmental Protection Agency, Science Advisory Board, Environmental Economics Advisory Committee, July 27, 2000. A copy of this document can be found in Docket A-99-06, Document IV-A-19.

Greenbaum, D., President, Health Effects Institute. "Dear Colleague" letter dated May 30, 2002. A copy of this letter can be found in Docket A-2000-01, Document IV-A-145, as an attachment to a letter from Lester D. Grant, PhD, to Dr. Philip K. Hopke, dated August 8, 2002.

Grosclaude, P. and N.C. Soguel. 1994. "Valuing Damage to Historic Buildings Using a Contingent Market: A Case Study of Road Traffic Externalities." *Journal of Environmental Planning and Management* 37: 279-287.

Holland, M., D. Forster, and M. Wenborn. 1999. Economic Evaluation of Proposals Under the UNECE Multi-effects and Multi-pollutant Protocol. Prepared for: European Commission, DGXI, Brussels and Luxembourg. January. Report no. AEAT-4587.

Hoskins, G., C. McCowan, R.G. Neville, G.E. Thomas, B. Smith, and S. Silverman. 2000. "Risk Factors and Costs Associated with and Asthma Attack." *Thorax*. 55: 19-24.

Hoskins, G., C. McCowan, R.G. Neville, G.E. Thomas, B. Smith, S. Silverman. 2000. Risk Factors and Costs Associated with an Asthma Attack. *Thorax*, 55: 19-24.

Hubbell, Bryan. 2002a. Senior Economist, OAQPS. Memorandum to Docket A-2000-01. Estimated NOx, SO2, and PM Emissions Health Damages for Heavy Duty Vehicle Emissions. April 22, 2002. A copy of this document can be found in Docket A-2000-01, Document IV-A-146.

Hubbell, Bryan. 2002b. Senior Economist, OAQPS. Memorandum to Trish Koman, OTAQ. Appendix to April 22 Memo "Estimated NOx, SO2, and PM Emissions Health Damages for Heavy Duty Vehicle Emissions": Alternative Estimates of Mortality and Chronic Bronchitis

Impacts. A copy of this document can be found in Docket A-2000-01, Document IV-A-202.

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

Jack, E., L.P. Boss, and W.M. Millington. 2000. Asthma - A Speaker's Kit for Public Health Professionals. Centers for Disease Control and Prevention, National Center for Health Statistics, Division of Environmental Hazards and Health Effects, Air Pollution and Respiratory Health Branch. Available at: http://www.cdc.gov/nceh/asthma/speakit/cover.htm.

Jones-Lee, M.W. 1989. *The Economics of Safety and Physical Risk.* Oxford: Basil Blackwell.

Jones-Lee, M.W., G. Loomes, D. O'Reilly, and P.R. Phillips. 1993. The Value of Preventing Non-fatal Road Injuries: Findings of a Willingness-to-pay National Sample Survey. TRY Working Paper, WP SRC2.

Krewski D, Burnett RT, Goldbert MS, Hoover K, Siemiatycki J, Jerrett M, Abrahamowicz M, White WH. 2000. Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality. Special Report to the Health Effects Institute, Cambridge MA, July 2000. A copy of this document can be found in Docket A-99-06, Document IV-G-75.

Krupnick, A.J., W. Harrington and B. Ostro. 1990. "Ambient Ozone and Acute Health Effects - Evidence From Daily Data." *Journal of Environmental Economics and Management* 18(1): 1-18.

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

Krupnick, A.J., A. Alberini, M. Cropper, N. Simon, B. O'Brien, R. Goeree, and M. Heintzelman. 2000. Age, Health, and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents. Resources for the Future Discussion Paper 00-37.

Krupnick, A.J. 2000. Personal Communication, December 5.

Kunzli, N., R. Kaiser, S. Medina, M. Studnicka, O. Chanel, P. Filliger, M. Herry, F. Horak Jr., V. Puybonnieux-Texier, P. Quenel, J. Schneider, R. Seethaler, J-C Vergnaud, and H. Sommer. 2000. Public-health Impact of Outdoor and Traffic-related Air Pollution: A European Assessment. *The Lancet*, 356: 795-801.

Lang, C., G. Yarwood, F. Lalonde, and R. Bloxam. 1995. *Environmental and Health Benefits of Cleaner Vehicles and Fuels*. Prepared for: Canadian Council of Ministers of the Environment Task Force on Cleaner Vehicles and Fuels, Winnipeg, Manitoba. October.

Laurence, J.A., W.A. Retzlaff, J.S. Kern, E.H.Lee, W.E. Hogsett, and D.A. Weinstein. 2000.

Predicting the regional impact of ozone and precipitation on the growth of loblolly pine and yellow-poplar using linked TREGRO and ZELIG models. For Ecological Management. In press.

Loehman, E.T., S.V. Berg, A.A. Arroyo, R.A. Hedinger, J.M. Schwartz, M.E. Shaw, R.W. Fahien, V.H. De, R.P. Fishe, D.E. Rio, W.F. Rossley, and A.E.S. Green. 1979. "Distributional Analysis of Regional Benefits and Cost of Air Quality Control." *Journal of Environmental Economics and Management* 6: 222-243.

Manuel, E.H., R.L. Horst, K.M. Brennan, W.N. Lanen, M.C. Duff and J.K. Tapiero. 1982. *Benefits Analysis of Alternative Secondary National Ambient Air Quality Standards for Sulfur Dioxide and Total Suspended Particulates, Volumes I-IV*. Prepared for US Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

McClelland, G., W. Schulze, D. Waldman, J. Irwin, D. Schenk, T. Stewart, L. Deck, and M. Thayer. 1993. *Valuing Eastern Visibility: A Field Test of the Contingent Valuation Method*. Prepared for Office of Policy, Planning and Evaluation, US Environmental Protection Agency. September.

McConnell, R., K. Berhane, F. Gilliland, S.J. London, H. Vora, E. Avol, W.J. Gauderman, H.G. Margolis, F. Lurmann, D.C. Thomas, and J.M. Peters. 1999. Air Pollution and Bronchitic Symptoms in Southern California Children with Asthma. *Environmental Health Perspectives*, 107(9): 757-760.

McConnell, R., K. Berhane, F. Gilliland, S.J. London, H. Vora, E. Avol, W.J. Gauderman, H.G. Margolis, F. Lurmann, D.C. Thomas, and J.M. Peters. 1999. Air Pollution and Bronchitic Symptoms in Southern California Children with Asthma. *Environmental Health Perspec*tives. 107(9): 757-760.

McDonnell, W.F., D.E. Abbey, N. Nishino and M.D. Lebowitz. 1999. "Long-term ambient ozone concentration and the incidence of asthma in nonsmoking adults: the ahsmog study." *Environmental Research*. 80(2 Pt 1): 110-21.

Mitchell, RC and RT Carson, 1989. Using Surveys to Value Public Goods: the Contingent Valuation Method. Resources for the Future. Washing ton DC.

NCLAN. 1988. Assessment of Crop Loss from Air Pollutants. (Eds. Walter W. Heck, O. Clifton Taylor and David T. Tingey) Elsevier Science Publishing Co.: New York, Pp. 1-5. (ERL,GB 639).

O'Conor, Richard M. and Glenn C. Blomquist, 1997. "Measurement of Consumer-Patient Preferences Using a Hybrid Contingent Valuation Method." *Journal of Health Economics* 16:667-683.

Ostro, B.D., M.J. Lipsett, J.K. Mann, H. Braxton-Owens, M.C. White, 1995. Air Pollution and

Asthma Exacerbations Among African-American Children in Los Angeles. *Inhalation Toxicology*, 7:711-722.

Ostro, B.D. 1987. Air Pollution and Morbidity Revisited: a Specification Test. *Journal of Environmental Economics Management.* 14: 87-98.

Ostro B.D. and S. Rothschild. 1989. “Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants.” *Environmental Research* 50:238-247.

Ostro, B.D., M.J. Lipsett, J.K. Mann, H. Braxton-Owens, M.C. White. 1995. Air Pollution and Asthma Exacerbations Among African-American Children in Los Angeles. *Inhalation Toxicology*, 7:711-722.

Pew Environmental Health Commission. 2000. *Attack Asthma: Why America Needs A Public Health Defense System to Battle Environmental Threats*. Johns Hopkins School of Public Health, Baltimore, MD.

Pew Environmental Health Commission. 2000. *Attack Asthma: Why America Needs A Public Health Defense System to Battle Environmental Threats.* John Hopkins School of Public Health, Baltimore, MD.

Pope, C.A., III, M.J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer, and C.W. Heath, Jr. 1995. “Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults.” *American Journal of Respiratory Critical Care Medicine* 151: 669-674.

Pope, C.A., III, D.W. Dockery, J.D. Spengler, and M.E. Raizenne. 1991. “Respiratory Health and PM_{10} Pollution: a Daily Time Series Analysis” *American Review of Respiratory Diseases* 144: 668-674.

Rowe, R.D. and L.G. Chestnut. 1986. “Oxidants and Asthmatics in Los Angeles: A Benefits Analysis--Executive Summary.” Prepared by Energy and Resource Consultants, Inc. Report to the US EPA, Office of Policy Analysis. EPA-230-09-86-018. Washington, DC March.

Samet JM, Zeger SL, Dominici F, Curriero F, Coursac I, Dockery DW, Schwartz J, Zanobetti A. 2000. The National Morbidity, Mortality and Air Pollution Study: Part II: Morbidity, Mortality and Air Pollution in the United States. Research Report No. 94, Part II. Health Effects Institute, Cambridge MA, June 2000. Docket A-2000-01, Documents IV-A-205 and 206.

Schwartz, J., Dockery, D.W., Neas, L.M., Wypij, D., Ware, J.H., Spengler, J.D., Koutrakis, P., Speizer, F.E., and Ferris, Jr., B.G. 1994. “Acute Effects of Summer Air Pollution on Respiratory Symptom Reporting in Children” *American Journal of Respiratory Critical Care* Medicine 150: 1234-1242.

Schwartz, J. 1993. “Particulate Air Pollution and Chronic Respiratory Disease” *Environmental Research* 62: 7-13.

Sheppard, L., D. Levy, G. Norris, T.V. Larson and J.Q. Koenig. 1999. Effects of ambient air pollution on nonelderly asthma hospital admissions in Seattle, Washington, 1987-1994. *Epidemiology*. Vol. 10(1): 23-30.

Sisler, J.F. 1996. Spatial and Seasonal Patterns and Long Term Variability of the Composition of the Haze in the United States: An Analysis of Data from the IMPROVE Network. Cooperative Institute for Research in the Atmosphere, Colorado State University; Fort Collins, CO July.

Smith, D.H., D.C. Malone, K.A. Lawson, L. J. Okamoto, C. Battista, and W.B. Saunders, 1997. "A National Estimate of the Economic Costs of Asthma." *American Journal of Respiratory Critical Care Medicine* 156: 787-793.

Smith, V.K., G.Van Houtven, and S. Pattanayak. 1999. "Benefit Transfer as Preference Calibration" *Resources for the Future Discussion Paper* 99-36.

Taylor, C.R., K.H. Reichelderfer, and S.R. Johnson. 1993. Agricultural Sector Models for the United States: Descriptions and Selected Policy Applications. Iowa State University Press: Ames, IA.

Thurston, G.D., M.L. Lippman, M.B. Scott, and J.M. Fine. 1997. Summertime Haze Air Pollution and Children with Asthma. *American Journal of Respiratory Critical Care Medicine,* 155: 654-660.

Thurston, G.D., M.L. Lippman, M.B. Scott, and J.M. Fine. 1997. Summertime Haze Air Pollution and Children with Asthma. *American Journal of Respiratory Critical Care Medicine,* 155: 654-660.

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

US Department of Commerce, Economics and Statistics Administration. 1992. Statistical Abstract of the United States, 1992: The National Data Book. 112th Edition, Washington, DC.

US Department of Commerce, Bureau of Economic Analysis. 1995. BEA Regional Projections to 2045: Vol. 1, States. Washington, DC US Govt. Printing Office, July 1995.

US Department of Health and Human Services, Centers for Disease Control and Prevention. 1999. National Center for Environmental Health Web Site. Available at http://www.cdc.gov/nceh/asthma/factsheets/asthma.htm

US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics. 1994. Vital Statistics of the United States, 1990. Volume II-Mortality. Hyattsville, MD.

US Department of Health and Human Services, Centers for Disease Control and Prevention.

1999. “Forecasted State-Specific Estimates of Self-Reported Asthma Prevalence -- United States, 1998.” *CDC-Morbidity and Mortality Weekly Report*, 47: 1022-1025.

US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics. 1999. National Vital Statistics Reports, 47(19).

US Department of Interior, 1986. Natural Resources Damage Assessment Rules and Regulations. (51 FR 148: 27725-27753. August 1, 1986)

US Department of Interior, 1991. Natural Resource Damage Assessment: Notice of Proposed Rulemaking. 56 FR 82: 19752-19753 April 29, 1991).

US Environmental Protection Agency, 1996b. *Review of the National Ambient Air Quality Standards for Particulate Matter: Assessment of Scientific and Technical Information.* Office of Air Quality Planning and Standards, Research Triangle Park, NC EPA report no. EPA/4521R-96-013. A copy of this document can be found in Docket A-99-06, Document II-A-23.

US Environmental Protection Agency, 1997e. *Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule.* US EPA, Office of Air Quality Planning and Standards. Research Triangle Park, NC. July. See EPA Air Docket A-96-56, Document No. VI-B-09.

US Environmental Protection Agency, 1998a. *Regulatory Impact Analysis for the NOx SIP Call, FIP and Section 126 Petitions, Volume 2: Health and Welfare Benefits*. Prepared by: Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, Research Triangle Park, NC December.

US Environmental Protection Agency, 1997a. *Regulatory Impact Analysis for Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed RH Rule.* Prepared by: Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, Research Triangle Park, NC. July.

US Environmental Protection Agency, 1998a. *Regulatory Impact Analysis for the NOx SIP Call, FIP, and Section 126 Petitions*. US EPA, Office of Air and Radiation. Washington, DC. EPA-452/R-98-003. December. See EPA Air Docket A-96-56, VI-B-09.

US Environmental Protection Agency, 1998b. *The Regional NOx SIP Call & Reduced Atmospheric Deposition of Nitrogen: Benefits to Selected Estuaries*, September.

US Environmental Protection Agency, 1999a. *The Benefits and Costs of the Clean Air Act, 1990-2010.* Prepared for US Congress by US EPA, Office of Air and Radiation/Office of Policy Analysis and Review, Washington, DC, November; EPA report no. EPA-410-R-99-001.

US Environmental Protection Agency, 1999b. *Regulatory Impact Analysis: Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline*

Sulfur Control Requirements. Prepared by: Office of Mobile Sources, Office of Air and Radiation, December.

US Environmental Protection Agency, 1999c. *Regulatory Impact Analysis for the Final Regional Haze Rule*. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April 22, 1999.

US Environmental Protection Agency, 1997f. "Response to Comments Made by AISI on EPA Methodology for Predicting PM2.5 from PM10." Memorandum to the docket from Terence Fitz-Simons (Office of Air Quality Planning and Standards, Air Quality Trends Analysis Group). February 6. See EPA Air Docket A-96-56, Document No. VI-B-09.

US Environmental Protection Agency, 1996a. *Proposed Methodology for Predicting PM2.5 from PM10 Values to Assess the Impact of Alternative Forms and Levels of the PM NAAQS*. Prepared by Terence Fitz-Simons, David Mintz and Miki Wayland (US Environmental Protection Agency, Office of Air Quality Planning and Standard, Air Quality Trends Analysis Group). June 26. See EPA Air Docket A-96-56, Document No. VI-B-09.

US Environmental Protection Agency, 1996b. *Review of the National Ambient Air Quality Standards for Ozone: Assessment of Scientific and Technical Information.* Office of Air Quality Planning and Standards, Research Triangle Park, NC EPA report no. EPA/4521R-96-007. Docket A-99-06, Document II-A-22.

US Environmental Protection Agency, 1994. Documentation for Oz-One Computer Model (Version 2.0). Prepared by Mathtech, Inc., under Contract No. 68D30030, WA 1-29. Prepared for US EPA, Office of Air Quality Planning and Standards. Research Triangle Park, NC. August

US Environmental Protection Agency, 1993. External Draft, Air Quality Criteria for Ozone and Related Photochemical Oxidants. Volume II. US EPA, Office of Health and Environmental Assessment. Research Triangle Park, NC, EPA/600/AP-93/004b.3v.

US Environmental Protection Agency, 1999b. *Regulatory Impact Analysis for the Final Regional Haze Rule*. Prepared by: Office of Air Quality Planning and Standards, Office of Air and Radiation, April.

US Environmental Protection Agency, 2000a. Technical Support Document for the Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements- Air Quality Modeling Analyses. December 2000.

US Environmental Protection Agency, 2000b. *Valuing Fatal Cancer Risk Reductions*. White Paper for Review by the EPA Science Advisory Board.

US Environmental Protection Agency,1997c. "Methodology Used to Create PM10 and PM2.5 Air Quality Databases for RIA Work." Memorandum from David Mintz, Air Quality Trends

Analysis Group, Office of Air Quality Planning and Standards to Allyson Siwik, Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards. July 15. See EPA Air Docket A-96-56, Document No. VI-B-09.

US Environmental Protection Agency, 1997b. *The Benefits and Costs of the Clean Air Act, 1970 to 1990*. Prepared for US Congress by US EPA, Office of Air and Radiation/Office of Policy Analysis and Review, Washington, DC

U.S. EPA Guidelines for the Health Risk Assessment of Chemical Mixtures. EPA Report No. 630/R-98/002. September 24, 1986. Federal Register 51(185) : 34014 - 34025. http://cfpub.epa.gov/ncea/

Valigura, Richard A., and W.T. Luke, R.S. Artz, B.B. Hicks. 1996. Atmospheric input to coastal areas: reducing the uncertainties. NOAA Coastal Ocean Program, Decision Analysis Series No. 9. NOAA Atmospheric Resources Laboratory, Silver Spring, MD.

Valiela, G. Collins, and J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, C.H. Sham. 1997. "Nitrogen loading from coastal watersheds to receiving estuaries: new method and application." *Ecological Applications* 7(2), pp. 358-380.

Viscusi, W.K. 1992. *Fatal Tradeoffs: Public and Private Responsibilities for Risk*. (New York: Oxford University Press).

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

Walsh, RG, DM Johnson and JR McKean, 1992. Benefits Transfer of Outdoor Recreation Demand Studies, 1968 - 1988. Water Resource Research. 28: 703-713.

White, JJ and Carroll, JN. (1998) Emissions from snowmobile engines using bio-based fuels and lubricants. Final Report. Prepared for State of Montana Department of Environmental Quality. Southwest Research Institute report #7383.

Whittemore, A.S. and E.L. Korn. 1980. Asthma and Air Pollution in the Los Angeles Area. *Am J Public Health*. Vol. 70: 687-696.

Yu, O., L. Sheppard, T. Lumley, J. Q. Koenig, and G.G. Shapiro. 2000. Effects of Ambient Air Pollution on Symptoms of Asthma in Seattle-Area Children Enrolled in the CAMP Study. *Environmental Health Perspectives*, 108(12): 1209-1214.
1.White, JJ and Carroll, JN. (1998) Emissions from snowmobile engines using bio-based fuels and lubricants. Final Report. Prepared for State of Montana Department of Environmental Quality. Southwest Research Institute report #7383.

2.U.S. EPA Guidelines for the Health Risk Assessment of Chemical Mixtures. EPA Report No. 630/R-98/002. September 24, 1986. Federal Register 51(185) : 34014 - 34025. http://cfpub.epa.gov/ncea/

3.White, JJ and Carroll, JN. (1998) Emissions from snowmobile engines using bio-based fuels and lubricants. Final Report. Prepared for State of Montana Department of Environmental Quality. Southwest Research Institute report #7383.

Buckingham, JP; White, JJ; and Carroll, JN. (1996) Development of snowmobile test cycle – final report. Southwest Research Institute report #7574.

4.Benignus, V, W Boyes, and P. Bushnell, US Environmental Protection Agency. National Health and Environmental Effects Research Laboratory. Memorandum to the Docket. Acute Behavioral Effects of Exposure to Toluene and Carbon Monoxide from Snowmobile Exhaust. September 2002.