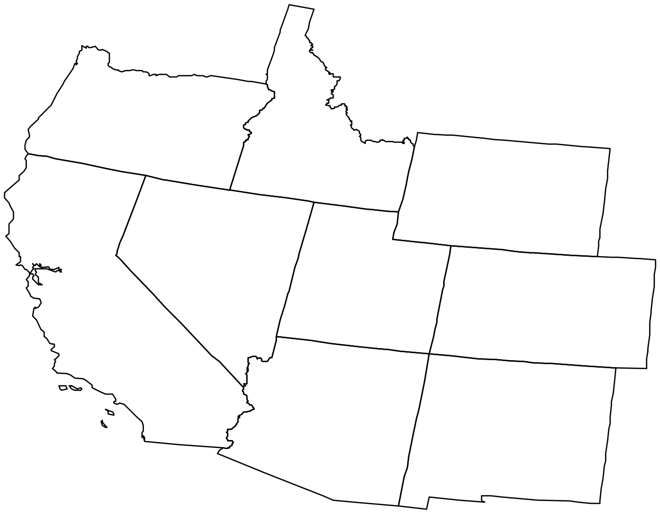
2018 Milestone Benefits Assessment of BART Reductions in 9 Western States



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2018 Milestone Benefits Assessment

The Western Regional Air Partnership (WRAP) is considering emission reduction milestones for reducing sulfur dioxide (SO_2) emissions from large industrial sources over the next 20 years. The WRAP is also considering a backstop cap-and-trade program that would go into effect if the emission milestones are not achieved. The WRAP was created as a broader successor organization to the Grand Canyon Visibility Transport Commission (GCVTC), which made recommendations to the U.S. Environmental Protection Agency (EPA) in June 1996 for improving visibility in 16 national parks and wilderness areas on the Colorado Plateau. The WRAP membership includes representatives from western States, Tribes, the U.S. Departments of Agriculture and Interior and the EPA. The emission reduction milestones and the backstop trading program were part of the GCVTC recommendations to EPA.

In the process of developing the milestones and the backstop trading program the WRAP analyzed the visibility changes and costs. Some stakeholders and WRAP members were asking the question, "What are the benefits of the reductions?" The EPA and the National Park Service (NPS) thought that it was important to understand all of the impacts of Best Available Retrofit Technology (BART) reductions in the 9-State area, and they have jointly funded this assessment. Specifically, this report summarizes EPA's analysis of the economic benefits of the 2018 milestone reduction of emissions from sources in the 9-State area.[1] In this report, we refer to the 170,000 ton reductions of SO_2 in 2018 using a command and control approach as the "EPA milestone reductions."

Summary of Results

The analysis presented here attempts to answer two questions:

1) What are the physical effects of changes in ambient air quality resulting from reductions in SO_2 emissions?

2) How much are the changes in air quality worth to U.S. citizens as a whole in monetary terms?

The results summarized in Table 1 provide another piece of information for the WRAP's consideration that shows significant public health and visibility benefits of the reductions they are contemplating.

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[1] The nine States include Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, and Wyoming. For the purposes of air quality modeling, 'nationwide' is taken to mean the 48 contiguous States.

Table 1. Total Quantified National Benefits in Millions of 1997 Dollars of a EPA's Milestone Reduction of 170,000 Tons SO_2

Health Benefits	$1,400
Class I Visibility Benefits	$ 300
Benefits we are not able to quantify	B_U
Total National Benefits	**$1,700 + B_U**

See section C for description of uncertainties and limitations.

The majority of the analytical assumptions used to develop our estimates have been reviewed and approved by the EPA Science Advisory Board (SAB). These methods have been used in a number of major rulemakings in which they have been reviewed by the Office of Management and Budget (OMB) and the public.

Nationally, the EPA milestone reductions would result in avoided particulate matter (PM) related health and welfare effects including the following:

- On the order of 200 premature deaths each year
- About 100 cases of chronic bronchitis in adults each year
- About 100 hospital admissions for cardiopulmonary disease and emergency room (ER) visits for asthma each year
- Approximately 5,000 asthma attacks in people with asthma each year
- About 11,000 respiratory symptoms primarily in children each year
- Approximately 40,000 days missed from work related to respiratory effects
- Hundreds of thousands of restricted activity days each year
- Other unquantified health effects
- Improvements in residential and recreational visibility
- Unquantified welfare benefits such as decreased acid deposition, and ecosystem and materials damage.

Introduction to Methodology

Although the primary environmental purpose of the milestone reductions is to help improve visibility in the 9-State area, significant health and monetary benefits will also be associated with changes in ambient levels of PM. While a broad range of adverse health and welfare effects have been associated with exposure to elevated PM levels, only subsets of these effects are selected for inclusion in the quantified benefit analysis.

The benefits assessment that we performed can be thought of as having four parts, each of which will be discussed briefly in the sections that follow. These four steps are:

1. Calculation of the impact that a Best Available Retrofit Technology (BART) command and control policy could have on regional source-specific inventories for SO_2.

2. Air quality modeling to determine the changes in ambient concentrations of PM and light extinction that will result from the reductions.

3. A benefits analysis to determine the changes in human health and welfare, both in terms of physical effects and monetary value, that result from the changes in air quality from changes in emissions of SO_2.

4. Calculation of the monetized benefits for purposes of comparison to the costs of the program.

EPA has used the best available information and analytical tools to quantify the expected changes in public health and environment and the economic benefits of the milestone reductions, given the constraints on time and resources available for the analysis. We have attempted to be as clear as possible in presenting our assumptions, sources of data, and sources of potential uncertainty in the analysis. Not all the benefits of the rule can be estimated with sufficient reliability to be quantified and included in monetary terms. In addition, simultaneous reductions of other pollutants such as HAP metals and the resulting benefits were not calculated. The omission of these items from the total of monetary benefits reflects our inability to measure or quantify them; it does not indicate the lack of importance of their benefits. When it is possible to qualitatively characterize a benefits category, we provide a discussion, although the benefit is not included in the estimate of total benefits.

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 this program. Where it is possible to quantify benefits, our measures are those associated with economic surplus in accepted applications of welfare economics. They measure value 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 analysis presents estimates of the potential benefits from the 170,000 ton SO_2 milestone reductions occurring in 2018 using an across-the-board, command and control approach, presented in detail in Section A.1. In addition, we also analyzed a second scenario which realizes a 140,000 ton reduction of SO_2 in 2018 and uses the Western Governors' Association's trading scenario (provided by ICF/Kaiser based on their Integrated Planning Model

(IPM) outputs dated July 20, 2000). The presentation here focuses mainly on the first scenario. The results from the second scenario are summarized in appendix A for comparison.

In our analysis, the 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 estimating emissions changes and specific health and welfare outcomes. The ways in which we deal with these uncertainties are discussed in Section C.

Figure 1 illustrates the steps necessary to link the milestone reductions with economic measures of benefits. In the first two steps we estimate the source-specific emission reductions needed to meet the EPA milestone reduction (e.g.,170,000 tons of SO_2). Next, the predicted emissions are used as inputs to an air quality model called the Source-Receptor (S-R) Matrix that predicts annual mean ambient concentrations of particulate matter. These concentrations depend on climatic conditions and basic chemical interactions. We have used the best available air quality model given time and resource constraints to estimate the changes in ambient concentrations (from baseline levels) that are used as the basis for this benefits assessment.

The predicted changes in ambient air quality then serve as inputs into functions to 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 2 lists the human health and welfare effects identified for PM. This list includes both those effects quantified (and/or monetized) in this analysis and those for which we are unable to provide quantified estimates. All of the effects related to HAPs that are controlled at the same time (e.g., mercury) are not quantified for this analysis. For changes in risks to human health from PM, quantified endpoints include changes in premature mortality and in a number of pollution-related non-fatal health effects. To estimate these endpoints, EPA combines changes in ambient air quality levels with epidemiological evidence about population health response to pollution exposure. For visibility welfare effects, the endpoints are defined as the annual average of the light extinction coefficent and deciview (a logarithmic transformation of light extinction coefficient.)

EPA’s benefits estimates of the effect of ambient pollution levels on all of these endpoints represent the best science available to the Agency. The majority of the analytical assumptions used to develop our estimates have been reviewed and approved by the EPA Science Advisory Board (SAB). These methods have been used in a number of major rulemakings in which they have been reviewed by the Office of Management and Budget (OMB) and the public. These methods have been used in the Regulatory Impact Analyses (RIAs) for Regional Haze, the mobile sources Tier 2/Gasoline Sulfur Rule, and the Section 126 NOx State Implementation Plan (SIP) call. Please refer to these documents and their associated technical support documents for more detailed discussion of the analytical approaches. However, like all estimates, they also contain unavoidable uncertainty, as does any prediction of the future. In Section C and in the subsections on health and welfare endpoints, this uncertainty is discussed and characterized.

Figure 1
Steps in the 2018 Milestone Benefits Assessment

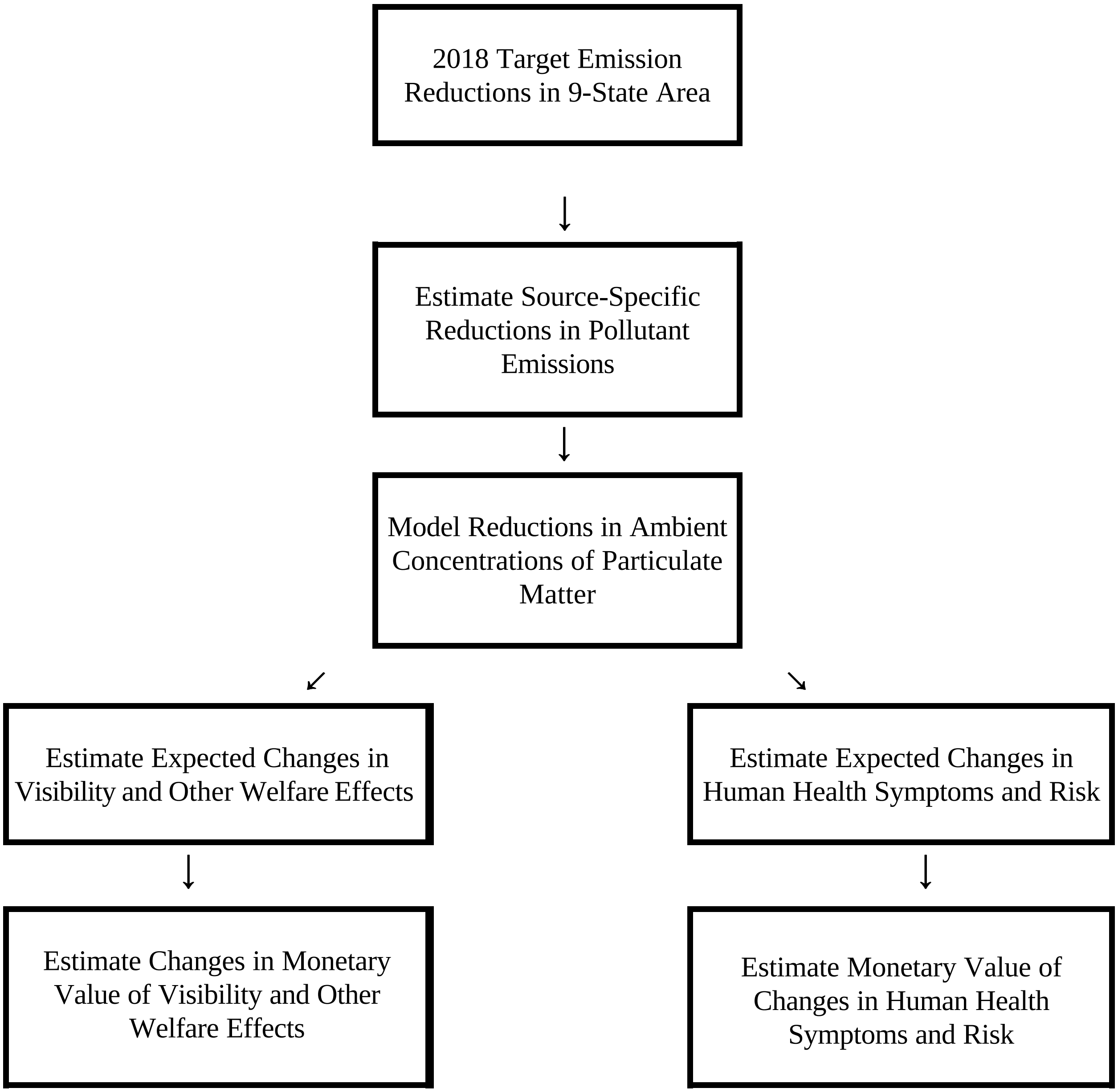


Table 2.
Human Health and Welfare Effects of Pollutants Affected by the 2018 Milestone Reductions

Pollutant	Quantified and Monetized Effects	Unquantified Effects
PM Health	Premature mortality Bronchitis - chronic and acute Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma Lower and upper respiratory illness Asthma attacks Minor restricted activity days/acute respiratory symptoms 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	Visibility in Class I areas	Soiling and Materials Damage Visibility (residential)
Sulfate Deposition Welfare		Impacts of acidic sulfate deposition on commercial forests Impacts of acidic deposition to commercial and recreational fishing Impacts of acidic deposition to recreation in terrestrial ecosystems Reduced existence values for currently healthy ecosystems
HAPS Health		Cancer Neurological effects Respiratory effects Reproductive effects Developmental effects Hematopoeitic effects Immunological effects Organ toxicity
HAPS Welfare		Direct toxic effects to animals, plants and systems Bioaccumlation in the food chain

This report is organized as follows: in Sections A and B we summarize emissions and air quality results including visibility changes, and we discuss the way that emissions and air quality changes are used as inputs to the benefits analysis. In Section C we introduce the kinds of benefits that are estimated, briefly present the techniques that are used, and provide a discussion of how we incorporate uncertainty into our analysis. In Section D, we describe individual health effects and report the results of the analysis for human health effects. In Section E, we describe individual welfare effects and report the results of the analysis for welfare effects. Finally, in Section F we report our estimates of total monetized benefits. In Appendix A we present results using a second scenario for comparison.

A. Emissions

In order to determine the air quality impact of the milestone reductions, we first calculated a baseline, then distributed the source-specific reductions in SO_2 emissions that would need to occur to meet the target. This Section describes how these inventories were determined.

1. EPA's Baseline Inventory

Initially, our plan was to utilize the same baseline and control scenarios being analyzed to estimate costs. However, we were unable to use the WGA baseline inventory because it did not contain a number of data fields necessary for air quality modeling. Instead, we used air quality modeling inventories developed for the recent Tier 2/Gasoline Sulfur rulemaking. This emissions inventory is discussed in Chapter III of the Tier 2/Gasoline Sulfur RIA (US EPA 1999) and in the supporting technical support document (TSD) referenced in that chapter. Readers desiring more information about the inventory methodologies or results should consult those documents for details. This baseline contains the following CAA programs (and assumptions):

- Tier 2/Gasoline Sulfur Rule
- NOx State Implementation Plan (SIP) Call
- Clean Air Act Title IV ("Acid Rain") reductions

Our baseline does not have the Tribal and "uncertainty" allocation that WGA included in their July 2000 baseline. Our baseline does not contain the 2007 Heavy Duty Diesel rule, as that has not been finalized at this time.

EPA's initial modeling inventory was for the year 2030. To arrive at the 2018 baseline, we interpolated linearly from the 2007 Tier 2 Control case and the 2030 Tier 2 Control case emissions inventories. The interpolation was performed using the following equation (VOC as an example):

$$VOC2018 = VOC2007 + 11/23\ (VOC2030 - VOC2007)$$

Area/Nonroad and mobile source files were interpolated at the county and source category level, while electric generating unit (EGU) and point source files were interpolated at the segment level (e.g., State + county + plant + point within plant + stack + segment). To better be able to handle some of the IPM-based scenarios, some minor adjustments were made in the baseline so that applying reductions would not yield negative SO_2 emissions. For more details see Pechan-Avanti, 2000.

The first column in Table 3 summarizes the baseline SO_2 tons by State.

2) EPA Milestone and Other Emissions Reduction Scenarios

Table 3 also summarizes the base case emissions by State and compares the various reduction scenarios. The third column presents the scenario that is the main subject of this analysis: the EPA milestone reductions. The derivation of the 170,000 ton reduction is described in more detail in this section.

For comparison there are three IPM-generated scenarios generated by the WGA:

- IPM-based 140,000 tons EPA Trading Scenario
- IPM-based 120,000 tons MTF Trading Scenario and
- IPM-based 140,000 tons WGA Command and Control Scenario.

For a discussion of the derivation of these three IPM-based scenarios, refer to ICF's July 2000 presentations to the Market Trading Forum. It should be noted that these scenarios and their baseline were evolving during ICF's analyses of cost. In order to have adequate time for a benefits assessment, EPA independently created its best estimate of a command and control scenario to meet the smaller end of EPA's suggested reductions, as described below. Due to resource and schedule constraints, EPA was not able to analyze fully all alternatives. As a result, this benefits assessment was not able to precisely match the WGA's scenarios. Nevertheless, we did analyze the IPM-based EPA trading scenario, and results are presented for comparison in the Appendix A.

Table 3. 2018 Base Case SO_2 Emissions and Control Scenario Reductions by State

State	Base Case Emissions (tons/year)	EPA Milestone Reductions (tons/year)	IPM-Based Scenarios		
			140,000 tons EPA Trading Scenario (tons/year)	MTF Target Trading Reductions (tons/year)	140,000 tons WGA Command and Control (tons/year)
Arizona	211,370	30,654	23,427	15,221	30,969
California	208,783	0	976	976	0
Colorado	142,424	37,852	30,992	30,293	26,518
Idaho	46,849	0	8,575	8,575	0
Nevada	78,777	0	99	28	0
New Mexico	179,777	24,481	17,880	13,600	18,709
Oregon	64,330	13,622	12,275	12,275	12,075
Utah	93,890	10,435	11,983	11,816	11,857
Wyoming	139,824	51,022	35,157	26,655	38,837
Total	**1,166,023**	**168,066**	**141,364**	**119,438**	**138,965**

The EPA milestone reduction scenario uses a command and control approach described in Section A.2.
The IPM-based scenarios were provided by the Western Governors Association and applied to the EPA baseline.
MTF is the Market Trading Forum.

Table 4 shows the detailed emission reductions for the EPA milestone reductions and their derivation. The EPA milestone reductions are SO_2 emission changes taken from EPA's April 10, 2000 letter to the WRAP's Market Trading Forum (MTF) (U.S EPA, 2000). In that letter, EPA proposed emission reductions ranging from 170,000 to 190,000 tons for BART. The smaller reduction in this range (i.e., 170,000 tons) was used in this analysis. EPA's estimate of emission reductions started from the MTF's spreadsheet, which provided emissions and control information for 72 BART sources (mostly utility and industrial boilers).

EPA made slightly more ambitious assumptions than the MTF regarding control efficiencies that could be obtained with BART in 2018 because it is achievable and more likely to lead to a least-cost approach. We assumed the following:

- New scrubbers (only for sources without existing controls) were estimated to achieve 90% control on average,
- Scrubber upgrades were assumed to be able to achieve 80% control for wet scrubbers and 85% for dry scrubbers.

Thus, about 90 percent of the BART emission reductions were taken from 16 sources (many with multiple boilers). The source-specific emission changes were applied to the EPA baseline discussed above and input to the S-R matrix to calculate the spatial patterns of sulfate concentration reductions.

B. Air Quality Impacts

This section summarizes the methods for and results of estimating air quality for the 2018 base and control scenarios. Based on the emissions inventories described above, ambient particulate matter (PM_{10} and $PM_{2.5}$) concentrations are projected from the S-R Matrix developed from the Climatological Regional Dispersion Model (CRDM). In Section B.1, we provide brief background on the S-R Matrix model. In Section B.2, we estimate PM air quality, and in Section B.3, we estimate visibility degradation. Visibility degradation (i.e., regional haze), is developed using empirical estimates of light extinction coefficients and efficiencies in combination with modeled reductions in pollutant concentrations.

1. PM Air Quality Modeling

EPA used the emissions inputs described above with a national-scale S-R Matrix to evaluate the effects of the milestone reductions on ambient concentrations of both PM_{10} and $PM_{2.5}$. Ambient concentrations of PM are composed of directly emitted particles and of secondary aerosols of sulfate, nitrate, ammonium, and organics. However, this analysis considers only SO_2 reductions.

Table 4. Lower End of EPA Range: Calculation of 170,000 ton SO2 Emission Reduction in 2018.

Technical assumptions (selected values shown below)

90%	*Control Efficiency with New Technology*
80%	*Control Efficiency for Wet Scrubber Upgrade*
85%	*Control Efficiency for Dry Scrubber Upgrade*
85%	*Tier Above Which No Further Controls*
1%	*Tier for Assuming a New Scrubber*
168,066	*BART Emission Reductions (tons)*

🟩 Key: For sources shaded in column A (e.g., rows 6 through 10), we used same assumptions as WRAP calculations.

No.	State	Unit	1996-98 Average Emissions	1996-98 Capacity Factor	2018 Capacity Factor	Current Control Efficiency	Additional criteria	Achievable Control Efficiency	Emission Reductions due to Achievable Controls
1	AZ	AEPCO Apache - Unit 2	3,148	78%	85%	43%	85%	85%	2,536
2	AZ	AEPCO Apache - Unit 3	2,404	70%	85%	43%	85%	85%	2,157
3	AZ	Arizona Public Service, Cholla - Unit 2	900	72%	85%	90%		90%	0
4	AZ	Arizona Public Service, Cholla - Unit 3	7,915	80%	85%	0%		90%	7,550
5	AZ	Arizona Public Service, Cholla - Unit 4	6,145	71%	85%	34%	90%	90%	6,242
6	AZ	Chemical Lime - Nelson: Kiln 1	181	64%	64%	80%		80%	0
7	AZ	Chemical Lime - Nelson: Kiln 2	275	58%	58%	80%		80%	0
8	AZ	Chemical Lime - Douglas: Kiln 4	37	24%	24%	80%		80%	0
9	AZ	Chemical Lime - Douglas: Kiln 5	634	86%	86%	61%		61%	0
10	AZ	Chemical Lime - Douglas: Kiln 6	0	77%	77%	0%		0%	0
11	AZ	SRP - Coronado UB1	8,309	67%	85%	66%	83%	83%	5,116
12	AZ	SRP - Coronado UB2	8,709	69%	85%	66%	83%	83%	5,207
13	AZ	Abitibi , Snowflake Division; #1 power boiler	0	1%	1%	0%		90%	0
14	AZ	Abitibi , Snowflake Division; #2 power boiler	1,959	83%	83%	55%		90%	1,523
15	AZ	Abitibi , Snowflake Division; #2 recovery boiler	359	100%	100%	0%		90%	323
16	CO	Conoco Inc. - Denver; FCC Unit Regenerator	912	100%	100%	0%		90%	821
17	CO	Conoco Inc. - Denver; Sulfur Recovery Unit	1,037	100%	100%	90%		98%	829
18	CO	Southwestern Portland Cement - Raw Material Dryer	32	100%	100%	0%		0%	0
19	CO	Southwestern Portland Cement - Kiln	128	100%	100%	0%		0%	0
20	CO	Colorado Springs Utilities - Drake #5	606	30%	85%	0%		90%	1,546
21	CO	Colorado Springs Utilities - Drake #6	1,939	66%	85%	0%		90%	2,247
22	CO	Colorado Springs Utilities - Drake #7	3,287	69%	85%	0%		90%	3,645
23	CO	Colorado Springs Utilities - Nixon #1	6,619	82%	85%	0%		90%	6,175
24	CO	Holnam Portland Cement #3	1,693	100%	100%	0%		0%	0
25	CO	Tristate Generation - Craig #1	4,489	80%	85%	66%	85%	85%	2,665
26	CO	Tristate Generation - Craig #2	4,365	78%	85%	66%	85%	85%	2,658
27	CO	Public Service CO - Comanche #1	5,680	69%	85%	0%		90%	6,298
28	CO	Public Service CO - Comanche #2	7,510	74%	85%	0%		90%	7,763
29	CO	Tri-Gen Energy - #4	877	100%	100%	0%		90%	789
30	CO	Tri-Gen Energy - #5	2,683	100%	100%	0%		90%	2,415
31	NM	PNM, San Juan, Boiler #1	8,216	85%	85%	75%		80%	1,643
32	NM	PNM, San Juan, Boiler #2	6,004	86%	86%	75%		80%	1,201
33	NM	PNM, San Juan, Boiler #3	13,873	96%	96%	75%		80%	2,775
34	NM	PNM, San Juan, Boiler #4	12,192	86%	86%	75%		80%	2,438
35	NM	Phelps Dodge, Hidalgo Smelter	31,833	88%	88%	96%		96%	0
36	NM	Giant Industries, Bloomfield Refinery	323	95%	95%	0%		90%	290
37	NM	Giant Refining, Ciniza Refinery, 4 B&W CO boiler	1,029	97%	97%	0%		0%	0

Table 4. Lower End of EPA Range: Calculation of 170,000 ton SO2 Emission Reduction in 2018.

Technical assumptions (selected values shown below)	
90%	***Control Efficiency with New Technology***
80%	***Control Efficiency for Wet Scrubber Upgrade***
85%	***Control Efficiency for Dry Scrubber Upgrade***
85%	***Tier Above Which No Further Controls***
1%	***Tier for Assuming a New Scrubber***
168,066	***BART Emission Reductions (tons)***

🟩 Key: For sources shaded in column A (e.g., rows 6 through 10), we used same assumptions as WRAP calculations.

No.	**State**	**Unit**	**1996-98 Average Emissions**	**1996-98 Capacity Factor**	**2018 Capacity Factor**	**Current Control Efficiency**	**Additional criteria**	**Achievable Control Efficiency**	**Emission Reductions due to Achievable Controls**
38	NM	Raton Public Service, Raton Pwr. Plt., 1 Erie	313	85%	85%	0%		90%	283
39	NM	El Paso Electric, Rio Grande Gen. Sta., 3	7	100%	100%	0%		90%	6
40	OR	Portland General Electric Company - Boardman	8,013.0	45%	85%	0%		90%	13,622
41	UT	PacifiCorp-Huntington Plant Unit#1	2,131	82%	85%	84%		84%	0
42	UT	PacifiCorp-Huntington Unit #2	10,476	77%	85%	0%		90%	10,435
43	UT	PacifiCorp-Hunter Unit #1	2,445	85%	85%	80%		80%	0
44	UT	PacifiCorp-Hunter Unit #2	2,430	80%	85%	90%		90%	0
45	WY	Pacificorp Wyodak Coal Power Plant (U1)	8,173	97%	97%	65%	DS	85%	4,670
46	WY	Black Hills Neil Simpson Coal Power Plant (U1)	963	65%	85%	0%		90%	1,136
47	WY	Pacificorp Naughton Coal Power Plant (U1)	6,098	88%	88%	0%		90%	5,488
48	WY	Pacificorp Naughton Coal Power Plant (U2)	7,987	83%	85%	0%		90%	7,362
49	WY	Pacificorp Naughton Coal Power Plant (U3)	5,062	82%	85%	77%		80%	688
50	WY	Pacificorp Dave Johnston Coal Power Plant (U3)	8,668	83%	85%	0%		90%	7,960
51	WY	Pacificorp Dave Johnston Coal Power Plant (U4)	6,695	89%	89%	54%	85%	85%	4,512
52	WY	Pacificorp Jim Bridger Coal Power Plant (U1)	5,265	76%	85%	77%	86%	86%	2,400
53	WY	Pacificorp Jim Bridger Coal Power Plant (U2)	5,682	82%	85%	77%	86%	86%	2,395
54	WY	Pacificorp Jim Bridger Coal Power Plant (U3)	5,464	79%	85%	77%	86%	86%	2,400
55	WY	Pacificorp Jim Bridger Coal Power Plant (U4)	3,202	77%	85%	82%	82%	82%	0
56	WY	Basin Electric Laramie River Coal Power Plant (U1)	3,421	74%	85%	81%	85%	85%	911
57	WY	Basin Electric Laramie River Coal Power Plant (U2)	3,014	72%	85%	81%	85%	85%	823
58	WY	Basin Electric Laramie River Coal Power Plant (U3)	3,512	70%	85%	81%	DS	85%	983
59	WY	Wyoming Refining TCC Feed Heater (H-03)	182	36%	36%	0%		98%	176
60	WY	Wyoming Refining TCC Plume Burner (H-05)	58	22%	22%	0%		98%	58
61	WY	Little America Oil Refinery #7 Boiler (BL-1415)	0	0%	1%	0%		98%	6
62	WY	FMC Corp. Trona Plant NS-1A Coal Boiler	2,379	52%	52%	0%		90%	2,156
63	WY	FMC Corp. Trona Plant NS-1B Coal Boiler	2,846	60%	60%	0%		90%	2,579
64	WY	General Chemical Trona Plant GR-2-L Coal Boiler	1,814	61%	61%	0%		90%	1,639
65	WY	General Chemical Trona Plant GR-3-W Coal Boiler	2,972	60%	60%	0%		90%	2,680
66	WY	FMC - Granger (Tg) Trona Plant #1 Coal Boiler (14)	94	23%	23%	85%		85%	0
67	WY	FMC - Granger (Tg) Trona Plant #2 Coal Boiler (15)	103	25%	25%	85%		85%	0
68	Navajo	Arizona Public Service, 4-Corners, Unit #1	4,032	75%	85%	72%	85%	85%	2,116
69	Navajo	Arizona Public Service, 4-Corners, Unit #2	3,207	64%	85%	72%	85%	85%	1,981
70	Navajo	Arizona Public Service, 4-Corners, Unit #3	4,314	67%	85%	72%	85%	85%	2,541
71	Navajo	Arizona Public Service, 4-Corners, Unit #4	13,692	75%	85%	72%		80%	4,428
72	Navajo	Arizona Public Service, 4-Corners, Unit #5	12,948	66%	85%	72%		80%	4,779
		Total	**303,965**						**168,066**

Table 4. Lower End of EPA Range: Calculation of 170,000 ton SO2 Emission Reduction in 2018.

Technical assumptions (selected values shown below)	
90%	***Control Efficiency with New Technology***
80%	***Control Efficiency for Wet Scrubber Upgrade***
85%	***Control Efficiency for Dry Scrubber Upgrade***
85%	***Tier Above Which No Further Controls***
1%	***Tier for Assuming a New Scrubber***
168,066	***BART Emission Reductions (tons)***

🟩 Key: For sources shaded in column A (e.g., rows 6 through 10), we used same assumptions as WRAP calculations.

No.	**State**	**Unit**	**1996-98 Average Emissions**	**1996-98 Capacity Factor**	**2018 Capacity Factor**	**Current Control Efficiency**	**Additional criteria**	**Achievable Control Efficiency**	**Emission Reductions due to Achievable Controls**

Notes

1. The box in the upper left displays our basic technical assumptions You may test other assumptions by entering different values in Column B, and the result will be displayed in the 9th row.

2. The 1% value for "tier for assuming a new scrubber" means that we assumed new scrubbers only for those sources with no scrubber in place.   If, for example, 70% was entered instead of 1%, all scrubbers achieving less than 70% would be assumed to be replaced with a new scrubber achieving 90%

3. The column labeled "additional criteria" provides two sets of info:
(a) whether an existing scrubber is a dry scrubber (there are only 2)
(b) the design efficiency in the DOE/EIA data base. We used this value if greater than the value indicated in the box at the upper left.
[For 4 Corners, units 1-3, and Dave Johnston unit 4, which are controlled by Venturi scrubbers, we assumed an achievable efficiency of 85%]

The S-R Matrix was developed from multiple simulations of the CRDM using meteorological data for 1990 coupled with emissions data from version 2.0 of the 1990 National Particulate Inventory (NPI). Relative to more sophisticated and resource-intensive three-dimensional modeling approaches, the CRDM and its associated S-R Matrix do not fully account for all the complex chemical interactions that take place in the atmosphere in the secondary formation of PM. Instead it relies on more simplistic species dispersion–transport mechanisms supplemented with chemical conversion at the receptor location.

The S-R Matrix consists of fixed-coefficients that reflect the relationship between annual average PM concentration values at a single receptor in each county (i.e., a hypothetical monitor sited at the county population centroid) and the contribution by PM species to this concentration from each emission source (E.H. Pechan, 1996). The modeled receptors include all U.S. county centroids as well as receptors in 10 Canadian provinces and 29 Mexican cities/states. The methodology used here for estimating PM air quality concentrations is detailed in Pechan-Avanti (2000) and is similar to the method used in the July 1997 PM and Ozone NAAQS RIA (U.S. EPA, 1997e) and the RIA for the final Regional Haze Rule (U.S. EPA, 1999a), and the Tier 2/Gasoline Sulfur Rule (US EPA, 1999c).

2. PM Air Quality Results

This section presents the projected reductions in particulate concentrations resulting from the EPA milestone reduction scenario. These results are presented for the following areas:

1) Grand Canyon Valley Transport Commission (GCVTC), which includes the 9 States where the emission reductions take place, and

2) Nationwide, which includes the 9 States as well as other U.S. counties where concentrations are reduced due to reduced transport of precursor emissions and PM.

The results presented here are associated with the EPA specified SO_2 emission reductions totaling roughly 170,000 tons in 2018. Appendix A summarizes similar results for the IPM-based EPA Trading scenario for comparison.

Table 5 provides a summary of the predicted ambient PM_{10} and $PM_{2.5}$ concentrations from the S-R Matrix for the 2018 base case and changes associated with EPA milestone reductions in the 9-State area and nationally. As expected with SO_2 emission reductions only, the S-R matrix results indicate that the change in PM concentrations associated with the EPA milestone reductions is composed almost entirely of reductions in fine particles ($PM_{2.5}$) with little or no reduction in coarse particles (PM_{10} less $PM_{2.5}$). Therefore, the observed changes in PM_{10} are composed primarily of changes in fine particulate sulfates. As shown, the average annual mean concentrations of $PM_{2.5}$ across counties in the 9-State area declines by 0.6 percent, or 0.08 $\mu g/m^3$

as a result of the controls. Nationally, the average annual mean concentrations of $PM_{2.5}$ across all

Table 5.

Summary of 2018 Base Case PM Air Quality and Changes Due to EPA Milestone Reductions

	9-State Region			*National (Counties with Changes)*		
Statistic	*2018 Base Case*	*Change*[a]	*Percent Change*	*2018 Base Case*	*Change*[a]	*Percent Change*
PM_{10} Annual Mean ($\mu g/m^3$)						
Minimum [b]	8.47	0.00	0.0%	6.33	0.00	0.0%
Maximum [b]	79.32	-0.04	-0.1%	139.35	-0.01	0.0%
Average	28.48	-0.08	-0.3%	23.52	-0.05	-0.2%
Median	26.60	-0.07	-0.2%	22.79	-0.03	-0.1%
Population-Weighted Average [c]	43.88	-0.04	-0.1%	33.05	-0.02	-0.1%
$PM_{2.5}$ Annual Mean ($\mu g/m^3$)						
Minimum [b]	0.82	0.00	0.0%	0.82	0.00	0.0%
Maximum [b]	28.10	-0.04	-0.2%	85.17	-0.01	0.0%
Average	10.46	-0.08	-0.6%	11.38	-0.05	-0.4%
Median	9.85	-0.07	-0.5%	11.46	-0.03	-0.3%
Population-Weighted Average [c]	14.70	-0.04	-0.3%	14.37	-0.02	-0.1%

[a] The change is defined as the control case value minus the base case value. The control case is the EPA milestone reduction of 170,000 SO_2 emissions in 2018.

[b] The base case minimum (maximum) is the value for the county with the lowest (highest) annual average. The change relative to the base case is the observed change for the county with the lowest (highest) annual average in the base case.

[c] Calculated by summing the product of the projected 2030 county population from Tier 2 RIA analysis (Abt Associates 1999a) and the estimated 2018 county PM concentration, and then dividing by the total population in the 48 contiguous States for the National calculation and by the total population in the 9 States for the regional calculation.

U.S. counties with observed changes declines by 0.4 percent, or 0.05 µg/m^3. Slightly lower absolute and relative declines are predicted for the population-weighted average for mean $PM_{2.5}$, which indicates more reductions in these concentrations across rural rather than urban areas.

Tables 6 and 7 provide additional insights on the changes in PM air quality resulting from the program. Table 6 focuses on the absolute change (in terms of µg/m^3) observed across individual U.S. counties in the 9-State area and nationally, while Table 7 focuses on the relative change (in terms of percent). As shown, the absolute reduction in annual mean PM_{10} concentration in the 9-State area ranged from a low of 0 µg/m^3 to and high of 0.84 µg/m^3, while the relative reduction ranged from a low of 0 percent to a high of 3.7 percent. (Note the minima and maxima could be separate counties for absolute and relative changes).

Table 6.
Summary of Absolute Changes in PM Air Quality Due to EPA Milestone Reductions

	Absolute Change from 2018 Base Case (µg/m^3)[a]	
Statistic	*9 State Region*	*National (of counties with changes)*
PM_{10} Annual Mean		
Minimum	0	-0.02
Maximum	-0.84	-0.84
Average	-0.08	-0.05
Median	-0.07	-0.03
Population-Weighted Average [b]	-0.04	-0.02
$PM_{2.5}$ Annual Mean		
Minimum	0	-0.02
Maximum	-0.83	-0.83
Average	-0.08	-0.05
Median	-0.07	-0.03
Population-Weighted Average [b]	-0.04	-0.02

[a] The absolute change is defined as the control case value minus the base case value. The control case is the EPA milestone reduction of 170,000 SO_2 emissions in 2018.

[b] Calculated by summing the product of the projected 2030 county population from Tier 2 RIA analysis (Abt Associates 1999a) and the estimated 2018 county PM absolute measure of change, and then dividing by the total population in the 48 contiguous States for the national calculation and by the total population in the 9 States for the regional calculation.

Table 7.
Summary of Relative Changes in PM Air Quality Due to EPA Milestone Reductions in 2018

	Relative Change from 2018 Base Case (%)[a]	
Statistic	*9 State Region*	*National (of counties with changes)*
PM_{10} Annual Mean		
Minimum	0.00%	-0.03%
Maximum	-3.68%	-3.68%
Average	-0.30%	-0.22%
Median	-0.28%	-0.17%
Population-Weighted Average [b]	-0.10%	-0.06%
$PM_{2.5}$ Annual Mean		
Minimum	0.00%	-0.08%
Maximum	-7.50%	-7.50%
Average	-0.81%	-0.49%
Median	-0.72%	-0.36%
Population-Weighted Average [b]	-0.31%	-0.14%

[a] The relative change is defined as the absolute change divided by the base case value, or the percentage change, for each county. The information reported in this column does not necessarily reflect the same county as is portrayed in the absolute change Table 6.

[b] Calculated by summing the product of the projected 2030 county population from Tier 2 RIA analysis (Abt Associates 1999a) and the estimated 2018 county PM relative measure of change, and then dividing by the total population in the 48 contiguous States for the national calculation and by the total population in the 9 States for the regional calculation.

Alternatively, for mean $PM_{2.5}$, the absolute reduction in the 9-State area ranged from 0 to 0.83 $\mu g/m^3$, while the relative reduction ranged from 0 to 7.5 percent. Nationally, the absolute and relative reductions in annual mean PM_{10} and $PM_{2.5}$ concentrations had the same range as the 9-State region but with lower mean and median statistics.

2. Visibility Degradation Estimates

Visibility degradation is often directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. To quantify changes in visibility, our analysis computes a light-extinction coefficient, based on the work of Sisler (1996), which shows the total fraction of light that is decreased per unit distance. This coefficient accounts for the scattering and absorption of light by both particles and gases, and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon (soot), and soil (Sisler, 1996).

Based upon the light-extinction coefficient, we also calculated a unitless visibility index, called a "deciview," which is used in the valuation of visibility. The deciview metric provides a linear scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview.

Because the visibility benefits analysis (see Section C) distinguishes between general regional visibility degradation and that particular to Federally-designated Class I areas (i.e., national parks, forests, recreation areas, wilderness areas, etc.), we separated estimates of visibility degradation into "residential" and "recreational" categories. The estimates of visibility degradation for the "recreational" category apply to Federally-designated Class I areas, while estimates for the "residential" category apply to non-Class I areas. Deciview estimates are developed from the estimated county-level changes in particulate matter generated from results of the S-R Matrix for the 2018 base case and milestone reductions. These deciview estimates are then aggregated to one of eight regions in the case of the residential category (as defined by the underlying study) and one of six regions in the case of the recreational category (as defined by Class I Visibility Regions described in more detail in Chestnut and Rowe (1990) and Pechan-Avanit (2000)). Taken together, the Southwest, California, and the Northwest would best approximate the 9-state area, but would also include Washington State and Montana.

Table 8 provides a summary of the visibility degradation estimates in terms of deciviews by residential category across U.S. regions. As shown, the national improvement of an annual average in residential visibility is 0.2 percent, or 0.04 deciviews. Predicted visibility improvements are the largest for the Southwest (0.5%), the Rocky Mountain (0.5%), and the Northwest (0.3%). Smaller visibility improvements are predicted in the South Central (0.3%) and California (0.2%).

Table 9 provides a summary of the visibility degradation estimates in terms of deciviews for Class I areas (i.e., recreational category) across U.S. visibility regions on an annual average. As shown, the national improvement in visibility for these areas is 0.3 percent, or 0.06 deciviews. Predicted visibility improvements are the largest for the Southwest (0.5%), the Rocky Mountain (0.6%), and the Northwest (0.4%). Smaller visibility improvements are predicted for California (0.2%) and negligible changes elsewhere (0.1%).

Table 8.
Summary of 2018 Visibility Degradation Estimates by Region: Residential (Annual Average Deciviews)

Study Regions	*2018 Base Case*	*Change*[a]	*Percent Change*
Southeast	23.65	-0.01	-0.1%
Southwest	17.16	-0.09	-0.5%
California	20.39	-0.03	-0.2%
Northeast	24.42	0.00	0.0%
North Central	22.19	-0.03	-0.1%
South Central	19.86	-0.06	-0.3%
Rocky Mountain	18.15	-0.10	-0.5%
Northwest	20.52	-0.09	-0.4%
National Average (unweighted)	21.59	-0.04	-0.2%

[a] The change is defined as the control case deciview level minus the base case deciview level. The control case is the EPA milestone reduction of 170,000 SO_2 emissions in 2018.

Table 9.
Summary of 2018 Visibility Degradation Estimates by Region: Recreational (Annual Average Deciviews)

Class I Visibility Regions	*2018 Base Case*	*Change*[a]	*Percent Change*
Southeast	22.40	-0.01	-0.1%
Southwest	17.23	-0.09	-0.5%
California	19.98	-0.03	-0.2%
Northeast/Midwest	21.10	-0.03	-0.1%
Rocky Mountain	17.54	-0.10	-0.6%
Northwest	21.50	-0.09	-0.4%
National Average (unweighted)	19.55	-0.06	-0.3%

[a] The change is defined as the control case deciview level minus the base case deciview level. The control case is the EPA milestone reduction of 170,000 SO_2 emissions in 2018.

C. Benefit Analysis

1. Methods for Estimating Benefits from Air Quality Improvements

Environmental and health economists have a number of methods for estimating the economic value of improvements in (or deterioration of) environmental quality. The method used in any given situation depends on the nature of the effect and the kinds of data, time and resources that are available for investigation and analysis. This section provides a brief overview of the methods EPA selected to monetize the benefits from the EPA milestone reductions. A more detailed discussion on all aspects summarized here is contained in the RIA for the Tier 2/Gasoline Sulfur rule (US EPA 1999c).

Our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary benefits research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Where appropriate, 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.

In general, economists tend to view an individual's willingness-to-pay for an 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.

More frequently than not, the economic benefits from environmental quality changes are not traded in markets, so direct measurement techniques can not be used. Avoided cost methods are ways to estimate the costs of pollution by using the expenditures made necessary by pollution damage. For example, if buildings must be cleaned or painted more frequently as levels of PM increase, then the appropriately calculated increment of these costs is a reasonable estimate of true economic benefits when PM levels are reduced. Avoided costs methods are also used to estimate some of the health-related benefits related to morbidity, such as hospital admissions (see Tier 2/Gasoline Sulfur RIA for details, US EPA 1999c).

Indirect market methods can also be used to infer the benefits of pollution reduction. The most important application of this technique for our analysis is the calculation of the value of a statistical life for use in the estimate of benefits from mortality reductions. There exists no market where changes in the probability of death are directly exchanged. However, people make decisions about occupation, precautionary behavior, and other activities associated with changes in the risk of death. By examining these risk changes and the other characteristics of people's choices, it is possible to infer information about the monetary values associated with changes in mortality risk. For measurement of health benefits, this analysis captures the WTP for most use and non-use values, with the exception of the value of avoided hospital admissions, which only captures the avoided cost of illness.

Estimating benefits for visibility and ecosystem services 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. The contingent valuation method (CVM) has been employed in the economics literature to value endpoint changes for both visibility and ecosystem functions (Chestnut and Dennis, 1997). CVM values endpoints by using carefully structured surveys to ask a sample of people what amount of compensation is equivalent to a given change in environmental quality. There is an extensive scientific literature and body of practice on both the theory and technique of CVM. EPA believes that well-designed and well-executed CVM studies are valid for estimating the benefits of air quality regulation.

2. 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. This analysis is no exception. 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 concentration-response (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 used in the first stage 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 benefits technical support document (TSD) for the RIA (Abt Associates, 1999b).

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

- gaps in scientific data and inquiry
- variability in estimated relationships, such as C-R functions, introduced through differences in study design and statistical modeling
- errors in projection for variables such as population growth rates
- errors due to misspecification of model structures, including the use of surrogate variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions
- biases due to omissions or other research limitations.

Table 10.
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.
2. Uncertainties Associated With PM Concentrations
-Estimating future-year baseline and daily PM concentrations. -Estimating the change in PM resulting from the control.
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 responsible for reported health effects have not been identified. -The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposures. -Possible confounding in the epidemiological studies of $PM_{2.5}$, effects with other factors (e.g., other air pollutants, weather, indoor/outdoor air, etc.). -The extent to which effects reported in the long-term 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
-What portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year, and what portion 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 well approximate what baseline incidence rates will be in the year 2018. -Projected population and demographics -- used to derive incidences – may not well approximate future-year population and demographics.
6. Uncertainties Associated With Economic Valuation
-Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have 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 benefit categories will cause total benefits to be underestimated.

Many benefits categories, while known to exist, do not have enough information available to provide a quantified or monetized estimate. The uncertainty regarding these endpoints is such that we could determine neither a primary estimate nor a plausible range of values. Some examples of known, but unmonetized effects include materials damage, residential visibility, and effects of acid deposition.

Our estimate of total benefits should be viewed as an approximate result because of the sources of uncertainty discussed above (see Table 10). The total benefits estimate may understate or overstate actual benefits of the rule. One way in which we reflect uncertainty in this analysis is by reducing the number of significant digits reported for the benefits estimate.

D. Assessment of Human Health Benefits

The most significant monetized benefits of reducing ambient concentrations of PM are attributable to reductions in health risks associated with air pollution. EPA's criteria document for PM lists numerous health effects known to be linked to ambient concentrations (US EPA, 1996a). This section describes individual effects and the methods EPA used to quantify and monetize changes in the expected number of incidences of various health effects.

In section D.1, we highlight key analytical assumptions, including how we handle the issue of health effects thresholds for premature mortality. In section D.2, we describe how we quantify and value changes in individual health effects. Finally, in section D.3, we present quantified estimates of the reductions in health effects resulting from the EPA milestone reductions and their associated monetary values.

1. Key Analytical Assumptions and Accounting for Potential Health Effect Thresholds

Key assumptions are the following:

- In this analysis we assume a causal relationship between PM and health endpoints listed in Table 2.

- Consistent with the most recent advice from EPA's Science Advisory Board, we do not impose a "no effects" threshold of 15 $\mu g/m^3$ or any other specific level for the PM-related health effects considered in this analysis.

- For some of the underlying health effects studies, the only available incidence information comes from the studies themselves. In these cases, incidence in the study population is assumed to represent typical incidence at the national level.

- We are assuming that concentration-response functions from other U.S. locations apply to these populations.

Furthermore, we make analytical adjustments to best match our analysis to the population studied. For example, because most PM studies that estimate C-R functions for mortality considered only non-accidental mortality, we adjusted county-specific baseline total mortality rates used in the estimation of PM-related premature mortality to provide a better estimate of county-specific non-accidental mortality. We multiplied each county-specific mortality rate by the ratio of national non-accidental mortality to national total mortality (0.93) (U.S. DHHS, Centers for Disease Control and Prevention, 1999).

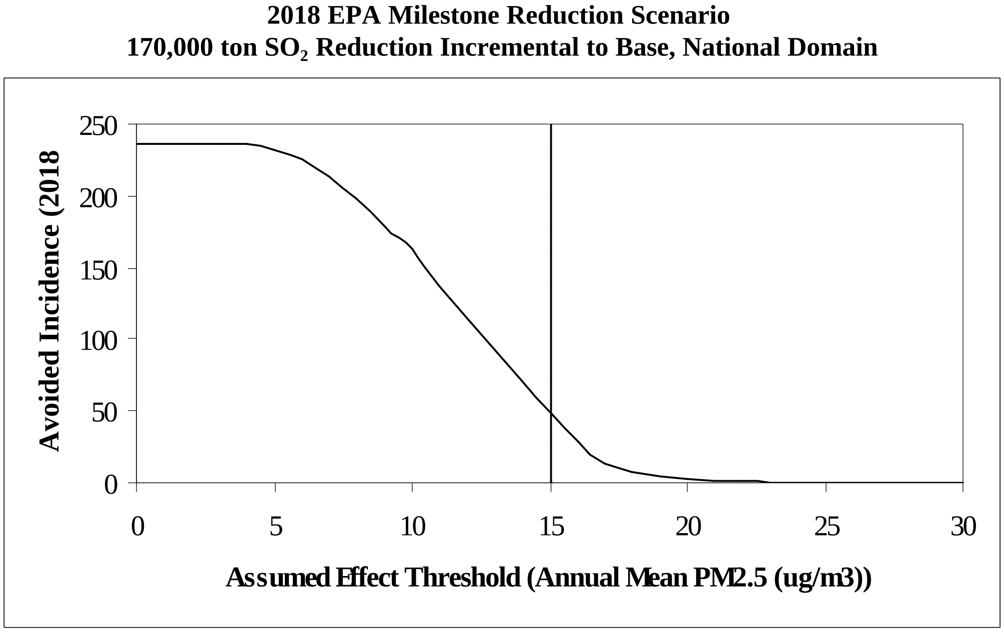
The shape of the concentration-response function is an important factor in our analysis. In clinical and epidemiological studies, C-R functions may be estimated with or without explicit thresholds. Air pollution levels below the threshold are assumed to have no associated health effects. When a threshold is not observed or assumed any exposure level is assumed to pose a non-zero risk of response to at least some segment of the population.

The possible existence of an effect threshold is a very important scientific question and issue for policy analyses. The most recent advice from EPA's Science Advisory Board is that there is currently no scientific basis for selecting a threshold of 15 $\mu g/m^3$ or any other specific level for the PM-related health effects considered in this analysis (EPA-SAB-Council-ADV-99-012, 1999). Therefore, for our benefits analysis of the 2018 milestone reductions, we assume there are no thresholds for modeling health effects because there is no adequate scientific evidence to support such a calculation.

Any of the PM-related health effects estimated in the analysis could have a threshold; however, a threshold for PM-related mortality would have the greatest impact on the overall benefits analysis. Figure 2 shows the effect of incorporating a range of possible thresholds, using 2018 PM levels and the Pope et al. (1995) study. Pope et al. did not explicitly include a threshold in their analysis. However, if the true mortality C-R relationship has a threshold, then Pope et al.'s slope coefficient would likely have been underestimated for that portion of the C-R relationship above the threshold. This would likely lead to an underestimate of the incidences of avoided cases above any assumed threshold level. It is difficult to determine the size of the underestimate without data on a likely threshold and without re-analyzing the Pope et al. data. Nevertheless, it is illustrative to show at what threshold levels benefits are significantly affected.

The distribution of premature mortality incidences in Figure 2 indicates that almost 70 percent of the premature mortality related benefits of the milestone reductions are due to changes in PM concentrations occurring above 10 $\mu g/m^3$, and around half are due to changes above 12 $\mu g/m^3$, the lowest observed level in the Pope, *et al.* study. Over 20 percent of avoided incidences are due to changes occurring above 15 $\mu g/m^3$.

Figure 2.
Impact of Existence of PM Health Effects Threshold on Avoided Incidences of Premature Mortality Estimated with the Pope et al. (1995) Concentration-Response Function



2. Quantifying and Valuing Individual Health Endpoints

While a broad range of adverse health effects have been associated with exposure to elevated PM levels, we include only a subset of health effects in this quantified benefit analysis. Health effects are excluded from this analysis for two reasons:

- The possibility of double counting (such as hospital admissions for specific respiratory diseases when we already analyze "all respiratory" category) or
- Lack of an established C-R relationship.

For this analysis, we rely on C-R functions estimated in published epidemiological studies relating adverse health effects to ambient air quality. The specific studies from which C-R functions are drawn are included in Table 11. When a single published study is selected as the basis of the C-R relationship between a pollutant and a given health effect, or "endpoint," applying the C-R function is straightforward. This is the case for most of the health endpoints selected for inclusion in the benefits analysis. A single C-R function may be chosen over other potential functions because the underlying epidemiological study used superior methods, data or techniques, or because the C-R function is more generalized and comprehensive.

When several estimated C-R relationships between a pollutant and a given health endpoint have been selected, they are combined or pooled to derive a single estimate of the relationship. Pooled C-R functions are used to estimate incidences of the following PM-related health effects: chronic bronchitis, hospital admissions from cardiovascular and respiratory causes, emergency room (ER) visits for asthma, and acute respiratory symptoms.

Table 11.
Endpoints and Peer Reviewed Studies

Endpoint	Study	Study Population
Mortality		
Long-term exposure mortality	Pope et al. (1995)	Adults, 30 and older
Chronic Illness		
Chronic Bronchitis	Multiple Studies[a]	Adults, Multiple Studies[a]
Hospital Admissions		
All Respiratory	Multiple Studies[a]	Multiple Studies[a]
Total Cardiovascular	Multiple Studies[a]	Multiple Studies[a]
Asthma-Related ER Visits	Multiple Studies[a]	Multiple Studies[a]
Other Illness		
Acute Bronchitis	Dockery et al. (1996)	Children, 8-12
Upper Respiratory Symptoms	Pope et al. (1991)	Asthmatic children, 9-11
Lower Respiratory Symptoms	Schwartz et al. (1994)	Children, 7-14
Asthma Attacks	Whittemore and Korn (1980)	All ages, asthmatics
Work Loss Days	Ostro (1987)	Adults, 18-65
Minor Restricted Activity Days / Any of 19 respiratory Symptoms	Multiple Studies[a]	Multiple Studies[a]

[a] For details see Tier 2/Gasoline Sulfur RIA (US EPA 1999c).

Whether the C-R relationship between a pollutant and a given health endpoint is estimated by a single function from a single study or by a pooled function of C-R functions from several studies, we apply that same C-R relationship at all locations in the U.S. Although the C-R relationship may in fact vary somewhat from one location to another (for example, due to differences in population susceptibilities or differences in the composition of PM), location-specific C-R functions are generally not available. While a single function applied everywhere may result in overestimates of incidence changes in some locations and underestimates in other locations, these location-specific biases will to some extent cancel each other out when the total national incidence change is calculated. It is not possible to know the extent or direction of the bias in the total incidence change based on the general application of a single C-R function everywhere.

The appropriate economic value of a change in a health effect depends on whether the health effect is viewed *ex ante* (before the effect has occurred) or *ex post* (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health affects by a fairly small amount for a large population. The appropriate economic measure is therefore *ex ante* WTP for changes in risk. However, epidemiological studies generally provide estimates of the expected number of incidences of a particular health effect avoided due to a reduction in air pollution. A convenient way to use this data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a measure is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature mortality amounts to $1 million ($100/0.0001 change in risk). Using this approach, the size of the affected population is automatically taken into account by the number of incidences predicted by epidemiological studies applied to the relevant population. The same type of calculation can produce values for statistical incidences of other health endpoints.

For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as an alternative estimate. For example, for the valuation of hospital admissions we use the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These costs of illness (COI) estimates generally understate the true value of avoiding a health effect. They tend to reflect the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect. Table 12 summaries the value estimates per health effect that we use in this analysis. Note that there is not a specific value for hospital admissions. There are a range of symptoms for which individuals are admitted, each of which has a different associated cost. The estimated benefit of avoided hospital admissions reflects the distribution of symptoms across the total incidence of hospital admissions.

For more detailed information about individual health endpoints and the C-R functions we have selected to provide quantified estimates of the avoided health effects associated with the milestone reductions, see the Tier 2/Gasoline Sulfur RIA (US EPA, 1999c). In the Tier 2 RIA we discuss how these changes in health effects should be valued and indicate the value functions selected to provide monetized estimates of the value of changes in health effects.

Table 12.
Unit Values Used for Economic Valuation of Health Endpoints

Health or Welfare Endpoint	Estimated Value Per Incidence (1997$) Central Estimate	Derivation of Estimates
Mortality	$5.9 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 Prospective analysis.
Chronic Bronchitis (CB)	$319,000	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		
All Respiratory (ICD codes: 460-519)	variable — function of the analysis	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 respiratory illnesses) reported in Elixhauser (1993).
All Cardiovascular (ICD codes: 390-429)	variable — function of the analysis	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	$280	COI estimate based on data reported by Smith et al. (1997).
Respiratory Ailments Not Requiring Hospitalization		
Upper Respiratory Symptoms (URS)	$23	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. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Acute Bronchitis	$55	Average of low and high values recommended for use in Section 812 analysis (IEc, 1994)
Asthma Attacks	$32	From Whittemore and Korn (1980). Mean of average WTP estimates for the four severity definitions of a "bad asthma day" (Rowe and Chestnut, 1986).

Health or Welfare Endpoint	Estimated Value Per Incidence (1997$) Central Estimate	Derivation of Estimates
Restricted Activity and Work Loss Days		
Work Loss Days (WLDs)	Variable	Regionally adjusted median weekly wage for 1990 divided by 5 (adjusted to 1997$) (U.S. Bureau of the Census, 1992).
Minor Restricted Activity Days (MRADs)	$47	Median WTP estimate to avoid 1 MRRAD – minor respiratory restricted activity day -- from Tolley et al.(1986) .

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

Applying the C-R and valuation functions described above to the estimated changes in PM yields estimates of the number of avoided incidences (i.e. premature deaths, cases, admissions, etc.) and the associated monetary values for those avoided incidences. These estimates are presented in Table 13 for the 170,000 ton SO_2 EPA milestone reductions. All of the monetary benefits are in constant 1997 dollars.

Not all known PM related health effects could be quantified or monetized. These unmonetized benefits are indicated by place holders, labeled B_1 and B_2. Unquantified physical effects are indicated by U_1 and U_2. 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 total national health benefits we are able to quantify total $1.35 billion. The largest monetized health benefit is associated with reductions in the risk of premature mortality. 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.

Table 13.
Estimated Annual Health Benefits Associated With Air Quality Changes Resulting from EPA Milestone Reductions in 2018

Using 170,000 ton SO_2 Reduction and EPA Command and Control Scenario

	9-State Area		National	
PM- Related Endpoint	**Avoided Incidence[c] (cases/year)**	**Monetary Benefits[d] (millions 1997$)**	**Avoided Incidence[c] (cases/year)**	**Monetary Benefits[d] (millions 1997$)**
Premature mortality[b] (adults, 30 and over)	80	400	240	$1,290
Chronic bronchitis	70	20	140	$40
Hospital Admissions from Respiratory Causes	30	$<1	70	$<1
Hospital Admissions from Cardiovascular Causes	10	$<1	30	$<1
Emergency Room Visits for Asthma	30	$<1	60	$<1
Acute bronchitis (children, 8-12)	260	$<1	550	$<1
Lower respiratory symptoms (LRS) (children, 7-14)	2,770	$<1	5,890	$<1
Upper respiratory symptoms (URS) (asthmatic children, 9-11)	2,730	$<1	5,860	$<1
Asthma attacks (all ages, asthmatics)	2,310	$<1	4,820	$<1
Work loss days (WLD) (adults, 18-65)	20,380	$<5	41,320	$<5
Minor restricted activity days (MRAD)/Acute respiratory symptoms	106,280	$<10	215,380	$10
Other PM-related health effects[e]	U_1	B_1	U_1	B_1
HAPS-related health effects[e]	U_2	B_2	U_2	B_2
Monetized Total Health-related Benefits[f]	—	\$460 + $\mathbf{B_H}$	—	\$1,350 + $\mathbf{B_H}$

[a] PM reductions are due to reductions in SO_2 resulting from the milestone reductions.

[b] The estimated value assumes the 5 year distributed lag structure described in the Tier 2 RIA (US EPA 1999).

[c] Incidences are rounded to the nearest 10.

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

[e] A detailed listing of unquantified PM heatlh effects is provided in Table 2.

[f] $\mathbf{B_H}$ is equal to the sum of all unmonetized categories, i.e. B_1+B_2

E. Assessment of Human Welfare Benefits

Particulate matter has documented effects on environmental quality that affect human welfare. These welfare effects include direct damages to property, either through impacts on material structures or by soiling of surfaces, indirect damages through alteration of ecosystem functions, and indirect economic damages through the loss in value of recreational experiences or the existence value of important resources. EPA's criteria document for PM lists numerous physical and ecological effects known to be linked to ambient concentrations of these pollutants (U.S. EPA, 1996a). For this analysis, we are only able to estimate the economic benefits associated with visibility improvements in Class I areas.

In section E.1, we describe how we quantify and value changes in visibility, both in federal Class I areas (national parks and wilderness areas) and in the areas where people live and work. In section E.2, we describe the damage to materials caused by particulate matter. Finally, in section E.3, we summarize the monetized estimates for welfare effects.

1. Visibility Benefits

Reductions in the concentrations of ambient particulate matter caused by the milestone reductions will change the visibility in much of the Western U.S. Visibility directly affects people's enjoyment of a variety of daily activities. Individuals value visibility both in the places they live and work, in the places they travel to for recreational purposes, and at sites of unique public value, such as the Grand Canyon. This section discusses the measurement of the economic benefits of visibility.

It is difficult to quantitatively define a visibility endpoint that can be used for valuation. Increases in PM concentrations cause increases in light extinction. Light extinction is a measure of how much the components of the atmosphere scatter or absorb light. More light extinction means that the clarity of visual images and visual range is reduced, *ceteris paribus.* Light absorption is a variable that can be accurately measured. Sisler (1996) created a unitless measure of visibility based directly on the degree of measured light absorption called the *deciview*. Deciviews are standardized for a reference distance in such a way that one deciview corresponds to a change of about 10 percent in available light. Sisler characterized a change in light extinction of one deciview as "a small but perceptible scenic change under many circumstances." Air quality models were used to predict the change in visibility, measured in deciviews, of the areas affected by the milestone reductions.[2]

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[2] A change of less than 10 percent in the light extinction budget represents a measurable improvement in visibility, but may not be perceptible to the eye in many cases. Some of the average regional changes in visibility are less than one deciview (i.e. less than 10 percent of the light extinction budget), and thus less than perceptible. However, this does not mean that these changes are not real or significant. Our assumption is then that individuals can place values on changes in visibility that may not be perceptible. This is quite plausible if individuals are aware that many regulations lead to small improvements in visibility which when considered together amount to

EPA considers benefits from two categories of visibility changes: residential visibility and recreational visibility. In both cases economic benefits are believed to consist of both use values and non-use values. The use values include the aesthetic benefits of better visibility, improved road and air safety, and enhanced recreation in activities like hunting and birdwatching. The non-use values are based on people's beliefs that the environment ought to exist free of human-induced haze. Non-use values may be a more important component of value for recreational areas, particularly national parks and monuments.

Residential visibility benefits are those that occur from visibility changes in urban, suburban, and rural areas, and also in recreational areas **not** listed as federal Class I areas.[3]

Recreational visibility improvements are those that occur specifically in federal Class I areas. A key distinction is that only those people living in residential areas are assumed to receive benefits from residential visibility, while all households in the U.S. are assumed to derive some benefit from improvements in Class I areas. Values are assumed to be higher if the Class I area is located close to their home.[4]

Only one existing study (Chestnut and Rowe1990a) provides defensible monetary estimates of the value of visibility changes in Class I areas. It utilizes the contingent valuation method. There has been a great deal of controversy and significant development of both theoretical and empirical knowledge about how to conduct CVM surveys in the past decade. In EPA's judgment, the Chestnut and Rowe study contains many of the elements of a valid CVM study and is sufficiently reliable to serve as the basis for monetary estimates of the benefits of visibility changes in recreational areas.[5] This study serves as an input to our estimates of the benefits of recreational visibility improvements in the primary benefits estimates.

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

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perceptible changes in visibility.

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

[4] For details of the visibility estimates discussed in this chapter, please refer to the benefits technical support document for the Regional Haze RIA.

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

improved visibility. In addition to the visibility change variable, the estimating equation also included household income as an explanatory variable.

The Chestnut and Rowe study did not measure values for visibility improvement in Class I areas outside the three regions. Their study covered 86 of the 156 Class I areas in the U.S. We can infer the value of visibility changes in the other Class I areas by transferring values of visibility changes at Class I areas in the study regions.

The estimated relationship from the Chestnut and Rowe study is only directly applicable to the populations represented by survey respondents. EPA used benefits transfer methodology to extrapolate these results to the population affected by the milestone reductions. A general willingness to pay equation for improved visibility (measured in deciviews) was developed as a function of the baseline level of visibility, the magnitude of the visibility improvement, and household income. The behavioral parameters of this equation were taken from analysis of the Chestnut and Rowe data. These parameters were used to calibrate WTP for the visibility changes resulting from the milestone reductions. The method for developing calibrated WTP functions is based on the approach developed by Smith, et al. (1999). Available evidence indicates that households are willing to pay more for a given visibility improvement as their income increases (Chestnut 1997). The benefits estimates here incorporate Chestnut's estimate that a 1% increase in income is associated with a 0.9% increase in WTP for a given change in visibility.[6]

We applied the methodology outlined above analyze the EPA milestone reduction scenario in three ways.

1) The first analysis is the most appropriate for understanding the economic benefits; namely, we used air quality changes across the country from these emission reductions in the 9-State area (e.g., transboundary transport was included), and we used the willingness to pay of the total national population.
2) Next, we restricted the air quality changes to just those changes within the 9-State area and estimated the benefits of those changes to the national population.
3) As with the second case, we restricted the air quality changes to just those changes within the 9-State area, and then restricted the estimate of benefits of those changes to the population within the 9-State area.

The resulting estimates of benefits would not be mutually exclusive; rather one could think of them as nested examinations of a single control scenario. Using the methodology outlined above in case #1, EPA estimates that the total national willingness to pay for the visibility improvements in Class I areas brought about by the 170,000 ton EPA milestone reductions is

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[6] These estimates of income elasticity are used to adjust the WTP for cross-sectional differences in income but not increases in income levels over time.

$320 million (1997$). This value includes the value to households living in the same state as the Class I area as well as values for all households in the U.S. living outside the State containing the Class I area.

We also analyzed the air quality changes limited to the 9-State area in two ways: limiting the population valuing visibility changes using a national population (case #2) and then limiting the population to people living in the 9-State area (case #3). The results of the analysis of case #2 yield a benefit of approximately $260 million for the national population valuing air quality changes in Class I areas within the 9 States only. The results of case #3 yield about $60 million of benefit when restricted to the 9-State population and air quality changes limited to Class I areas within the 9 States only.

One major source of uncertainty for the visibility benefit estimate is the benefits transfer process used. Judgments used to choose the functional form and key parameters of the estimating equation for willingness to pay for the affected population could have significant effects on the size of the estimates. Assumptions about how individuals respond to changes in visibility that are either very small, or outside the range covered in the Chestnut and Rowe study, could also affect the results.

2. Benefits from Reductions in Materials Damage

The milestone reductions are expected to produce economic benefits in the form of reduced materials damage. There are two important categories of these benefits. Household soiling refers to the accumulation of dirt, dust, and ash on exposed surfaces. Criteria pollutants also have corrosive effects on commercial/industrial buildings and structures of cultural and historical significance. The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

Previous EPA benefit analyses, including that for the Regional Haze RIA, have been able to provide quantitative estimates of household soiling damage. Following an SAB recommendation (EPA-SAB-Council-ADV-003, 1998), EPA has determined that the existing data (based on consumer expenditures from the early 1970's) is too out of date to provide a reliable enough estimate of household soiling damages in 2018.

EPA is unable to estimate any benefits to commercial and industrial entities from reduced materials damage. Nor is EPA able to estimate the benefits of reductions in PM-related damage to historic buildings and outdoor works of art. Existing studies of damage to this latter category in Sweden (Grosclaude and Soguel, 1994) indicate that these benefits could be an order of magnitude larger than household soiling benefits (Morey et al., 1997).

3. Benefits from Reduced Ecosystem Damage

The effects of air pollution on the health and stability of ecosystems are potentially very important, but are at present poorly understood and difficult to measure. The reductions in SO_2 caused by the final rule could produce significant unquantified benefits (US EPA 1999b).

These unquantified benefits are in the form of healthier ecological resources, including stream, river, lake and estuarine ecosystems; forests and wetland ecosystems; and agricultural ecosystems. These benefits are important because of both the intrinsic value of these ecological resources and the intimate link between human health and the vitality of our sustaining ecosystems.

For example, reductions in acid deposition and mercury may reduce adverse effects on aquatic ecosystems including finfish, shellfish, and amphibian mortality and morbidity and reduced acidification of poorly buffered systems. Ecological protection, in turn, can enhance human welfare through improvements in commercial and recreational fishing, wildlife viewing, maintenance of biodiversity, improvements in drinking water quality, and the myriad of ecological services ecosystems provide (US EPA 1999b).

4. Estimated Values for Welfare Endpoints

Applying the valuation methods described above to the estimated changes in PM in 2018 yields estimates of the value of changes in visibility. These estimates are presented in Table 14. All of the monetary benefits are in constant 1997 dollars.

We are unable to provide primary monetized estimates of residential visibility, household soiling, materials damage, or ecosystem damage, in addition to the other welfare effects listed in Table 2. These unmonetized benefits are indicated by placeholders, labeled B_3 to B_7. The estimate of total monetized welfare benefits is thus equal to the subset of monetized welfare benefits plus $\mathbf{B_W}$, the sum of the unmonetized welfare benefits.

Total monetized welfare related benefits are around \$260 million for air quality changes limited to only in the 9-State area and \$320 million nationally. Monetized welfare benefits are roughly one fifth the magnitude of monetized health benefits. However, due to the difficulty in quantifying and monetizing welfare benefits, a higher proportion of welfare benefits are not monetized. It is thus inappropriate to conclude that welfare benefits are unimportant just by comparing the estimates of the monetized benefits.

Table 14.
Estimated Annual Monetary Values for Welfare Effects Associated With Improved Air Quality Resulting from the EPA Milestone Reductions in 2018

Endpoint	**9-State Monetary Benefits (millions 1997$)[a]**	**National Monetary Benefits (millions 1997$)[a]**
Recreational Visibility (Federal Class I areas)	$260	$320
Residential Visibility	B_3	B_3
Household Soiling	B_4	B_4
Materials Damage	B_5	B_5
Other PM-related welfare effects[b]	B_6	B_6
HAPS-related welfare effects[b]	B_7	B_7
Total Monetized Welfare-related Benefits[c]	$260+$\mathbf{B_W}$	$320+$\mathbf{B_W}$

[a] Rounded to the nearest 10 million dollars. The 9-State value analyzes air quality changes limited to the 9 States (i.e., no transboundary transport) as valued by the national population.

[b] A detailed listing of unquantified PM and HAPS related welfare effects is provided in Table 2.

[c] $\mathbf{B_W}$ is equal to the sum of all unmonetized welfare categories, i.e. $B_3+B_6+...+B_n$.

F. Total Benefits

We provide our primary estimate of benefits for each health and welfare endpoint and the resulting 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 point 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 milestone reductions are listed in Table 15, along with a breakdown of benefits by endpoint. Note that the value of endpoints known to be affected by 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. 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.

Our primary estimate of total national monetized benefits for the milestone reductions is $1.7 billion, of which approximately $1.3 billion is the benefits of reduced premature mortality risk from PM exposure. Total monetized benefits are dominated by the benefits of reduced mortality risk. Mortality related benefits account for over two thirds of total monetized benefits followed by visibility (about 20 percent) and chronic bronchitis (about 3 percent).

Table 15.
EPA Preferred National Estimate of Annual Quantified Benefits Associated With Improved Air Quality Resulting from the EPA Milestone Reductions in 2018

170,000 Ton Reduction of SO_2 in 9-State Area

Endpoint related to PM	**Avoided Incidence[c,d] (cases/year)**	**Monetary Benefits[e] (millions 1997$)**
Premature mortality[a,h] (adults, 30 and over)	240	$1,290
Chronic bronchitis	140	$40
Hospital Admissions from Respiratory Causes	70	$<1
Hospital Admissions from Cardiovascular Causes	30	$<1
Emergency Room Visits for Asthma	60	$<1
Acute bronchitis (children, 8-12)	550	$<1
Lower respiratory symptoms (children, 7-14)	5,890	$<1
Upper respiratory symptoms (asthmatic children, 9-11)	5,860	$<1
Asthma attacks (asthmatics, all ages)	4,820	$<1
Work loss days (adults, 18-65)	41,320	$<5
Minor restricted activity days /Acute resp. symptoms	215,380	$10
Other health effects[d]	$U_1+U_2+U_3+U_4$	$B_1+B_2+B_3+B_4$
Recreational visibility (86 Class I Areas)	—	$320
Residential visibility	—	B_5
Household soiling damage	—	B_6
Materials damage	—	B_7
Other welfare effects[f]	—	B_8
Monetized Total[g,h]		$1,670+**B**

[a] It is assumed that the Pope, et al. C-R function for premature mortality captures all PM mortality benefits. Also note that the valuation assumes the 5 year distributed lag structure.

[b] PM reductions are due to the milestone emission reductions in SO_2 . [c] Incidences are rounded to the nearest 10.

[d] The U_i are the incidences for the unquantified category i. [e] Dollar values are rounded to the nearest 10 million dollars.

[f] A detailed listing of unquantified PM, related heatlh and welfare effects is provided in Table 2.

[g] **B** is equal to the sum of all unmonetized categories, i.e. $B_1+B_2+...+B_n$.

[h] These estimates are based on the EPA preferred approach for valuing reductions in premature mortality, the VSL approach.

The scenario used is EPA's command and control emissions reductions of 170,000 tons in 2018.

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Appendix A. Results for the IPM-Based EPA Trading Scenario

Comparison of Results

Table A-1. Total National Benefits in Millions of 1997 Dollars

	EPA Milestone Reductions Command and Control Scenario, 170,000 tons	**IPM-based EPA Trading Scenario, 140,000 tons**
Health Benefits	1,400	1,100
Welfare Benefits	300	270
Benefits we were unable to quantify	B_u	B_u
Total	**\$1,700 + B_u**	**\$1,400 + B_u**

Results include both health and welfare endpoints. Please see section C of the main report for description of uncertainties and limitations.

Description of IPM-based EPA Trading Scenario

Table A-2 summarizes the base case emissions by State and compares the various reduction scenarios. The third column presents scenario that is the main subject of this analysis: the EPA milestone reductions. Listed for comparison are three IPM-generated scenarios generated by the WGA. For a discussion of the derivation of these three IPM-based scenarios, refer to ICF's July 2000 presentations to the Market Trading Forum.

In addition, we calculated the benefits from the scenario depicted in the fourth column: the IPM-based 140,000 tons EPA Trading Scenario, provided by the WGA.

The following tables summarize the results for this scenario:

Table A-3.	**Summary of 2018 Base Case PM Air Quality and Changes: EPA Trading Scenario**
Table A-4.	**Summary of 2018 Absolute Changes in PM Air Quality: EPA Trading Scenario**
Table A-5.	**Summary of 2018 Relative Changes in PM Air Quality: EPA Trading Scenario**
Table A-6.	**Summary of 2018 Residential Visibility Degradation Estimates by Region: EPA Trading Scenario (Annual Average Deciviews)**
Table A-7.	**Summary of 2018 Recreational Visibility Degradation Estimates by Region: EPA Trading Scenario (Annual Average Deciviews)**
Table A-8.	**Estimated Annual Health Benefits Associated With Air Quality Changes: EPA Trading Scenario**
Table A-9.	**Estimated Annual Monetary Values for Welfare Effects Associated With Improved Air Quality: EPA Trading Scenario**
Table A-10.	**EPA Preferred National Estimate of Annual Quantified Benefits Associated With Improved Air Quality: EPA Trading Scenario**

Table A-2. 2018 Base Case SO_2 Emissions and Control Scenario Reductions by State

State	Base Case Emissions (tons/year)	EPA Milestone Reductions (tons/year)	IPM-Based Scenarios		
			140,000 tons EPA Trading Scenario (tons/year)	MTF Target Trading Reductions (tons/year)	140,000 tons WGA Command and Control (tons/year)
Arizona	211,370	30,654	23,427	15,221	30,969
California	208,783	0	976	976	0
Colorado	142,424	37,852	30,992	30,293	26,518
Idaho	46,849	0	8,575	8,575	0
Nevada	78,777	0	99	28	0
New Mexico	179,777	24,481	17,880	13,600	18,709
Oregon	64,330	13,622	12,275	12,275	12,075
Utah	93,890	10,435	11,983	11,816	11,857
Wyoming	139,824	51,022	35,157	26,655	38,837
Total	**1,166,023**	**168,066**	**141,364**	**119,438**	**138,965**

The EPA milestone reduction scenario uses a command and control approach described in Section A.2. The IPM-based scenarios were provided by the Western Governors Association and applied to the EPA baseline. MTF is the Market Trading Forum.

Table A-3.
Summary of 2018 Base Case PM Air Quality and Changes: EPA Trading Scenario

	9-State Region			*National (Counties with Changes)*		
Statistic	*2018 Base Case*	*Change*[a]	*Percent Change*	*2018 Base Case*	*Change*[a]	*Percent Change*
PM_{10} Annual Mean (μg/m^3)						
Minimum [b]	8.47	0.00	0.0%	6.33	0.00	0.0%
Maximum [b]	79.32	-0.03	-0.1%	139.35	0.00	0.0%
Average	28.48	-0.07	-0.3%	23.52	-0.05	-0.2%
Median	26.60	-0.06	-0.2%	22.79	-0.03	-0.1%
Population-Weighted Average [c]	43.88	-0.03	-0.1%	33.05	-0.02	-0.1%
$PM_{2.5}$ Annual Mean (μg/m^3)						
Minimum [b]	0.82	0.00	0.0%	0.82	0.00	0.0%
Maximum [b]	28.10	-0.03	-0.2%	85.17	0.00	0.0%
Average	10.46	-0.07	-0.7%	11.38	-0.05	-0.4%
Median	9.85	-0.06	-0.7%	11.46	-0.03	-0.3%
Population-Weighted Average [c]	14.70	-0.03	-0.2%	14.37	-0.02	-0.1%

[a] The change is defined as the control case value minus the base case value. The control case is the 140,000 ton IPM-based EPA Trading scenario.

[b] The base case minimum (maximum) is the value for the county with the lowest (highest) annual average. The change relative to the base case is the observed change for the county with the lowest (highest) annual average in the base case.

[c] Calculated by summing the product of the projected 2030 county population from Tier 2 RIA analysis (Abt Associates, 1999a) and the estimated 2018 county PM concentration, and then dividing by the total population in the 48 contiguous states.

Table A-4.
Summary of 2018 Absolute Changes in PM Air Quality: EPA Trading Scenario

	Absolute Change from 2018 Base Case ($\mu g/m^3$)[a]	
Statistic	*9 State Region*	*National*
PM_{10} Annual Mean		
Minimum	-0.02	-0.02
Maximum	-0.74	-0.74
Average	-0.07	-0.04
Median	-0.06	-0.03
Population-Weighted Average [b]	-0.03	-0.01
$PM_{2.5}$ Annual Mean		
Minimum	-0.02	-0.02
Maximum	-0.74	-0.74
Average	-0.07	-0.04
Median	-0.06	-0.03
Population-Weighted Average [b]	-0.03	-0.01

[a] The absolute change is defined as the control case value minus the base case value.

[b] Calculated by summing the product of the projected 2030 county population from Tier 2 RIA analysis (Abt Associates, 1999a) and the estimated 2018 county PM absolute/relative measure of change, and then dividing by the total population in the 48 contiguous States for the national calculation and by the total population in the 9 States for the regional calculation.

Table A-5.
Summary of 2018 Relative Changes in PM Air Quality: EPA Trading Scenario

	Relative Change from 2018 Base Case (%)[a]	
Statistic	*9 State Region*	*National*
PM_{10} Annual Mean		
Minimum	-0.03%	-0.03%
Maximum	-3.24%	-3.24%
Average	-0.26%	-0.18%
Median	-0.23%	-0.13%
Population-Weighted Average [b]	-0.09%	-0.04%
$PM_{2.5}$ Annual Mean		
Minimum	-0.12%	-0.08%
Maximum	-6.69%	-6.69%
Average	-0.70%	-0.37%
Median	-0.65%	-0.26%
Population-Weighted Average [b]	-0.24%	-0.08%

[a] The relative change is defined as the absolute change divided by the base case value, or the percentage change, for each county. The information reported in this column does not necessarily reflect the same county as is portrayed in the absolute change column.

[b] Calculated by summing the product of the projected 2030 county population from Tier 2 RIA analysis (Abt Associates, 1999a) and the estimated 2018 county PM relative measure of change, and then dividing by the total population in the 48 contiguous States for the national calculation and by the total population in the 9 States for the regional calculation.

Table A-6.
Summary of 2018 Residential Visibility Degradation Estimates by Region: EPA Trading Scenario (Annual Average Deciviews)

Study Regions	*2018 Base Case*	*Change*[a]	*Percent Change*
Southeast	23.65	-0.01	-0.1%
Southwest	17.16	-0.09	-0.4%
California	20.39	-0.03	-0.1%
Northeast	24.42	0.00	0.0%
North Central	22.19	-0.02	-0.1%
South Central	19.86	-0.05	-0.3%
Rocky Mountain	18.15	-0.08	-0.5%
Northwest	20.52	-0.08	-0.4%
National Average (unweighted)	**21.59**	**-0.03**	**-0.2%**

[a] The change is defined as the control case deciview level minus the base case deciview level.

Table A-7.
Summary of 2018 Recreational Visibility Degradation Estimates by Region: EPA Trading Scenario (Annual Average Deciviews)

Class I Visibility Regions	*2018 Base Case*	*Change*[a]	*Percent Change*
Southeast	22.40	-0.01	0.0%
Southwest	17.23	-0.07	-0.4%
California	19.98	-0.03	-0.2%
Northeast/Midwest	21.10	-0.02	-0.1%
Rocky Mountain	17.54	-0.09	-0.5%
Northwest	21.50	-0.08	-0.4%
National Average (unweighted)	19.55	-0.05	-0.3%

[a] The change is defined as the control case deciview level minus the base case deciview level.

Table A-8.
Estimated Annual Health Benefits Associated With Air Quality Changes Resulting from 140,000 ton SO_2 Reduction and IPM-Based EPA Trading Scenario

	9-State Area		National	
PM- Related Endpoint	**Avoided Incidence[c] (cases/year)**	**Monetary Benefits[d] (millions 1997$)**	**Avoided Incidence[c] (cases/year)**	**Monetary Benefits[d] (millions 1997$)**
Premature mortality[b] (adults, 30 and over)	70	390	190	$1,050
Chronic bronchitis	60	20	120	$40
Hospital Admissions from Respiratory Causes	30	$<1	50	$<1
Hospital Admissions from Cardiovascular Causes	10	$<1	30	$<1
Emergency Room Visits for Asthma	20	$<1	50	$<1
Acute bronchitis (children, 8-12)	240	$<1	460	$<1
Lower respiratory symptoms (LRS) (children, 7-14)	2,480	$<1	4,930	$<1
Upper respiratory symptoms (URS) (asthmatic children, 9-11)	2,460	$<1	4,930	$<1
Asthma attacks (all ages, asthmatics)	2,080	$<1	4,010	$<1
Work loss days (WLD) (adults, 18-65)	18,210	$<5	34,110	$<5
Minor restricted activity days (MRAD)/Acute respiratory symptoms	94,960	$<5	177,770	$10
Other PM-related health effects[e]	U_1	B_1	U_1	B_1
HAPS-related health effects[e]	U_2	B_2	U_2	B_2
Monetized Total Health-related Benefits[f]	—	$410 + $\mathbf{B_H}$	—	$1,100 + $\mathbf{B_H}$

[a] PM reductions are due to reductions in SO_2 resulting from the EPA trading scenario.

[b] The estimated value assumes the 5 year distributed lag structure described in the Tier 2 RIA (US EPA 1999).

[c] Incidences are rounded to the nearest 10.

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

[e] A detailed listing of unquantified PM heatlh effects is provided in Table 2.

[f] $\mathbf{B_H}$ is equal to the sum of all unmonetized categories, i.e. B_1+B_2

Table A-9.
Estimated Annual Monetary Values for Welfare Effects Associated With Improved Air Quality Resulting from 140,000 ton SO_2 Reduction and IPM-Based EPA Trading Scenario

Endpoint	**9-State Monetary Benefits (millions 1997$)[a]**	**National Monetary Benefits (millions 1997$)[a]**
Recreational Visibility (Federal Class I areas)	$220	$270
Residential Visibility	B_3	B_3
Household Soiling	B_4	B_4
Materials Damage	B_5	B_5
Other PM-related welfare effects[b]	B_6	B_6
HAPS-related welfare effects[b]	B_7	B_7
Total Monetized Welfare-related Benefits[c]	\$220+$\mathbf{B_W}$	\$270+$\mathbf{B_W}$

[a] Rounded to the nearest 10 million dollars. The 9-State value analyzes air quality changes limited to the 9 States (i.e., no transboundary transport) as valued by the national population.

[b] A detailed listing of unquantified PM and HAPS related welfare effects is provided in Table 2.

[c] $\mathbf{B_W}$ is equal to the sum of all unmonetized welfare categories, i.e. $B_3+B_6+...+B_n$.

Table A-10.
EPA Preferred National Estimate of Annual Quantified Benefits Associated With Improved Air Quality Resulting from 140,000 ton SO_2 Reduction
IPM-Based EPA Trading Scenario

Endpoint related to PM	Avoided Incidence[c,d] (cases/year)	Monetary Benefits[e] (millions 1997$)
Premature mortality[a,h] (adults, 30 and over)	190	$1,050
Chronic bronchitis	110	$40
Hospital Admissions from Respiratory Causes	50	$<1
Hospital Admissions from Cardiovascular Causes	30	$<1
Emergency Room Visits for Asthma	50	$<1
Acute bronchitis (children, 8-12)	460	$<1
Lower respiratory symptoms (children, 7-14)	4,930	$<1
Upper respiratory symptoms (asthmatic children, 9-11)	4,930	$<1
Asthma attacks, (asthmatics, all ages)	4,010	$<1
Work loss days (adults, 18-65)	34,110	$<5
Minor restricted activity days /Acute resp. symptoms	177,770	$10
Other health effects[d]	$U_1+U_2+U_3+U_4$	$B_1+B_2+B_3+B_4$
Recreational visibility (86 Class I Areas)	—	$270
Residential visibility	—	B_5
Household soiling damage	—	B_6
Materials damage	—	B_7
Other welfare effects[f]	—	B_8
Monetized Total[g,h]		$1,370+**B**

[a] It is assumed that the Pope, et al. C-R function for premature mortality captures all PM mortality benefits. Also note that the valuation assumes the 5 year distributed lag structure.

[b] PM reductions are due to the milestone emission reductions in SO_2 . [c] Incidences are rounded to the nearest 10.

[d] The U_i are the incidences for the unquantified category i. [e] Dollar values are rounded to the nearest 10 million dollars.

[f] A detailed listing of unquantified PM, related heatlh and welfare effects is provided in Table 2.

[g] **B** is equal to the sum of all unmonetized categories, i.e. $B_1+B_2+...+B_n$.

[h] These estimates are based on the EPA preferred approach for valuing reductions in premature mortality, the VSL approach.

The scenario used is an IPM-based EPA Trading scenario of emissions reductions of 140,000 tons in 2018.