Regulatory Impact Analysis (RIA)
for the final Transport Rule
Docket ID No. EPA-HQ-OAR-2009-0491

Regulatory Impact Analysis for the Federal Implementation Plans to Reduce Interstate Transport of Fine Particulate Matter and Ozone in 27 States; Correction of SIP Approvals for 22 States

U.S. EPA
Office of Air and Radiation

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CHAPTER 1

EXECUTIVE SUMMARY

This Regulatory Impact Analysis (RIA) presents the health and welfare benefits, costs, and other impacts of the Transport Rule focusing primarily on 2014.

1.1 Key Findings

> The final Transport Rule will lower sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions from the electric power industry in 28 eastern states starting in 2012[1]. In 2014, this final rule will have annual benefits (in 2007$) between $120 to $280 billion using a 3% discount rate and $110 and $250 billion using a 7% discount rate. At these respective discount rates, the annual social costs are $0.8 billion and the annual quantified net benefits are $120 to $280 billion or $110 to $270 billion. The benefits outweigh social costs from 150 up to 350 to 1, or from 110 up to 335 to 1. The benefits result primarily from 13,000 to 34,000 fewer $PM_{2.5}$ and ozone-related premature mortalities. There are some costs and important benefits that EPA could not monetize. Upon considering these limitations and uncertainties, it remains clear that the benefits of the Transport Rule are substantial and far outweigh the costs. The annualized private compliance costs to the power industry in 2014 are $0.8 billion. Employment impacts associated with the final rule are estimated to be small. The benefits of the Transport Rule in 2012 are greater than in 2014 due, in part, to the final rule expediting emissions reductions that otherwise would have occurred in 2014.

The benefits and costs in 2014 of the selected remedy (air quality-assured trading) in the final rule are in Table 1-1. This selected remedy covers the electric power industry and allows interstate emissions trading of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) in the covered states as listed in section 2.2 of this RIA.

1 As finalized, the rule requires emission reductions in 27 states. EPA issued a supplemental proposal to request comment on requiring ozone-season NOx reductions in additional states; including the states addressed in the supplemental proposal, the total number of states covered by the Transport Rule would be 28.

Table 1-1. Summary of EPA's Estimates of Benefits, Costs, and Net Benefits of the Selected Remedy in the Transport Rule in 2014[a] (billions of 2007$)

Description	Estimate (3% Discount Rate)	Estimate (7% Discount Rate)
Social costs[b]	$0.81	$0.81
Social benefits[c,d]	$120 to $280 + B	$110 to $250 + B
Health-related benefits:	$110 to $270 + B	$100 to $250 + B
Visibility benefits[e]	$4.1	$4.1
Net benefits (benefits-costs)	$120 to $280	$110 to $250

[a] All estimates are rounded to two significant digits and represent annualized benefits and costs anticipated for the year 2014. For notational purposes, unquantified benefits are indicated with a "B" to represent the sum of additional monetary benefits and disbenefits. Data limitations prevented us from quantifying these endpoints, and as such, these benefits are inherently more uncertain than those benefits that we were able to quantify. A listing of health and welfare effects is provided in Table 1-5. Estimates here are subject to uncertainties discussed further in the body of the document.

[b] Social costs are estimated using the MultiMarket model, the model employed by EPA in this RIA to estimate economic impacts of the industries outside the electric power sector. This model does not estimate indirect impacts associated with a regulation such as this one. Details on the social cost estimates can be found in Chapter 8 and Appendix B of this RIA.

[c] The reduction in premature mortalities account for over 90% of total monetized benefits. Benefit estimates are national except for visibility that covers Class I areas. Valuation assumes discounting over the SAB-recommended 20-year segmented lag structure described in Chapter 5. Results reflect 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses (U.S. EPA, 2010; OMB, 2003). The estimate of social benefits also includes CO_2 related benefits calculated using the social cost of carbon, discussed further in Chapter 5.

[d] Potential benefit categories that have not been quantified and monetized are listed in Table 1-5.

[e] Over 99% of visibility-related benefits occur within Class-1 areas located in the Eastern U.S.

1.1.1 Health Benefits

The final Transport Rule is expected to yield significant health benefits by reducing emissions of two key contributors to fine particle and ozone formation. Sulfur dioxide contributes to the formation of fine particle pollution ($PM_{2.5}$), and nitrogen oxide contributes to the formation of both $PM_{2.5}$ and ground-level ozone.

Our analyses suggest this would yield benefits in 2014 of $120 to $280 billion (based on a 3 percent discount rate) and $110 to $250 billion (based on a 7 percent discount rate). The estimated benefits of this rule are substantial, particularly when viewed within the context of the total public health burden of $PM_{2.5}$ and ozone air pollution. A recent EPA analysis estimated that 2005 levels of $PM_{2.5}$ and ozone were responsible for between 130,000 and 320,000 PM2.5-related and 4,700 ozone-related premature deaths, or about 6.1% of total deaths (based on the lower end of the avoided mortality range) from all causes in the continental U.S. (Fann et al. 2011). This same analysis attributed almost 200,000 non-fatal heart attacks, 90,000 hospital admissions due to respiratory or cardiovascular illness and 2.5 million cases of aggravated asthma among children--among many other impacts. We estimate the Transport Rule to reduce the number of $PM_{2.5}$-related premature deaths in 2014 by between 13,000 and 34,000, 15,000 non-fatal heart attacks, 8,700 fewer hospital admissions and 400,000 fewer cases of aggravated asthma. By 2014, in combination with other federal and state air quality actions, the Transport Rule will address a substantial fraction of the total public health burden of $PM_{2.5}$ and ozone air pollution. However, the benefits and costs reported in this RIA reflect only the incremental costs and benefits of the Transport Rule.

We also estimate substantial additional health improvements for children from reductions in upper and lower respiratory illnesses, acute bronchitis, and asthma attacks. See Table 1-2 for a list of the annual reduction in health effects expected in 2014 and Table 1-3 for the estimated value of those reductions. In these tables we summarize the benefits according to whether they accrue within or beyond the Transport region (Eastern part of the US covered by the final rule). While not analyzed here, we expect the benefits in 2012 (the first compliance year for this final rule) to be significantly larger than those modeled for 2014 because of the much greater incremental SO_2 reductions in 2012 compared to 2014 from the base case. This occurs because the final rule expedites the adoption of SO_2 emissions controls that are planned in the base case to occur after 2012 and be underway by 2014.

Table 1-2: Estimated Reduction in Incidence of Adverse Health Effects of the Selected remedy (95% confidence intervals)[A]

Health Effect		*Within transport region*	*Beyond transport region*	*Total*
PM-Related endpoints				
Premature Mortality				
	Pope et al. (2002) (age >30)	13,000 (5,200—21,000)	33 (5—60)	13,000 (5,200—21,000)
	Laden et al. (2006) (age >25)	34,000 (18,000—49,000)	84 (31—140)	34,000 (18,000—49,000)
	Infant (< 1 year)	59 (-47—160)	0.15 (-0.2—0.5)	59 (-47—160)
Chronic Bronchitis		8,700 (1,600—16,000)	23 (-5—50)	8,700 (1,600—16,000)
Non-fatal heart attacks (age > 18)		15,000 (5,600—24,000)	40 (7—72)	15,000 (5,600—24,000)
Hospital admissions—respiratory (all ages)		2,700 (1,300—4,000)	5 (2—9)	2,700 (1,300—4,000)
Hospital admissions—cardiovascular (age > 18)		5,700 (4,200—6,600)	15 (10—19)	5,800 (4,200—6,600)
Emergency room visits for asthma (age < 18)		9,800 (5,800—14,000)	21 (7—36)	9,800 (5,800—14,000)
Acute bronchitis (age 8-12)		19,000 (-630—37,000)	50 (-29—130)	19,000 (-660—37,000)
Lower respiratory symptoms (age 7-14)		240,000 (120,000—360,000)	630 (130—1,100)	240,000 (120,000—360,000)
Upper respiratory symptoms (asthmatics age 9-18)		180,000 (57,000—310,000)	480 (-25—980)	180,000 (57,000—310,000)
Asthma exacerbation (asthmatics 6-18)		400,000 (45,000—1,100,000)	1,100 (-250—2,900)	400,000 (45,000—1,100,000)
Lost work days (ages 18-65)		1,700,000 (1,500,000—1,900,000)	4,300 (3,500—5,200)	1,700,000 (1,500,000—1,900,000)
Minor restricted-activity days (ages 18-65)		10,000,000 (8,400,000—11,000,000)	26,000 (20,000—32,000)	10,000,000 (8,400,000—12,000,000)

Ozone-related endpoints				
Premature mortality				
Multi-city and NMMAPS	Bell et al. (2004) (all ages)	27 (11—42)	0.1 (0.01—0.3)	27 (11—42)
	Schwartz et al. (2005) (all ages)	41 (17—64)	0.2 (0.1—0.4)	41 (17—65)
	Huang et al. (2005) (all ages)	37 (17—57)	0.2 (0.1—0.4)	37 (17—57)
Meta-analyses	Ito et al. (2005) (all ages)	120 (78—160)	0.6 (0.3—0.9)	120 (79—160)
	Bell et al. (2005) (all ages)	87 (48—130)	0.5 (0.2—0.8)	87 (48—130)
	Levy et al. (2005) (all ages)	120 (89—150)	0.7 (0.4—0.9)	120 (90—160)
Hospital admissions—respiratory causes (ages > 65)		160 (21—280)	1.2 (0.1—2.3)	160 (21—290)
Hospital admissions—respiratory causes (ages <2)		83 (43—120)	0.5 (0.2—0.8)	84 (43—120)
Emergency room visits for asthma (all ages)		86 (-2—260)	0.4 (-0.2—1.4)	86 (-2—260)
Minor restricted-activity days (ages 18-65)		160,000 (80,000—240,000)	910 (240—1,600)	160,000 (80,000—240,000)
School absence days		51,000 (22,000—73,000)	290 (59—490)	51,000 (22,000—74,000)

[A] Estimates rounded to two significant figures; column values will not sum to total value.
[B] The negative estimates for certain endpoints are the result of the weak statistical power of the study used to calculate these health impacts and do not suggest that increases in air pollution exposure result in decreased health impacts.

Table 1-3: Estimated Economic Value of Health and Welfare Benefits (95% confidence intervals, billions of 2007$)[A,B]

Health Effect	*Pollutant*	*Within transport region*	*Beyond transport region*[C]	*Total*
Premature Mortality (Pope et al. 2002 PM mortality and Bell et al. 2004 ozone mortality estimates)				
3% discount rate	$PM_{2.5}$ & O_3	$100 ($8.3—$320)	$0.3 ($0.01—$0.9)	$100 ($8.3—$320)
7% discount rate	$PM_{2.5}$ & O_3	$94 ($7.5—$280)	$0.2 ($0.01—$0.8)	$94 ($7.5—$290)
Premature Mortality (Laden et al. 2006 PM mortality and Levy et al. 2005 ozone mortality estimates)				
3% discount rate	$PM_{2.5}$ & O_3	$270 ($23—$770)	$0.7 ($0.05—$2)	$270 ($23—$770)
7% discount rate	$PM_{2.5}$ & O_3	$240 ($21—$700)	$0.6 ($0.05—$1.8)	$240 ($21—$700)
Chronic Bronchitis	$PM_{2.5}$	$4.2 ($0.2—$19)	$0.01 ($-0.003--$0.06)	$4.2 ($0.2—$19)
Non-fatal heart attacks				
3% discount rate	$PM_{2.5}$	$1.7 ($0.3—$4.2)	$0.004 ($0.003—$0.01)	$1.7 ($0.3—$4.2)
7% discount rate	$PM_{2.5}$	$1.3 ($0.3—$3.1)	$0.004 ($0.002—$0.001)	$1.3 ($0.3—$3.1)
Hospital admissions—respiratory	$PM_{2.5}$ & O_3	$0.04 ($0.02—$0.06)	---	$0.04 ($0.02—$0.06)
Hospital admissions—cardiovascular	$PM_{2.5}$	$0.09 ($0.01—$0.2)	---	$0.09 ($0.01—$0.2)
Emergency room visits for asthma	$PM_{2.5}$ & O_3	$0.003 ($0.002—$0.006)	---	$0.003 ($0.002—$0.006)
Acute bronchitis	$PM_{2.5}$	$0.008 (<$-0.01—$0.02)[D]	---	$0.008 (<$-0.01—$0.02)[c]
Lower respiratory symptoms	$PM_{2.5}$	$0.004 ($0.002—$0.009)	---	$0.004 ($0.002—$0.009)
Upper respiratory symptoms	$PM_{2.5}$	$0.005 (<$0.01—$0.014)	---	$0.005 (<$0.01—$0.014)
Asthma exacerbation	$PM_{2.5}$	$0.02 ($0.002—$0.08)	---	$0.02 ($0.002—$0.08)
Lost work days	$PM_{2.5}$	$0.2 ($0.17—$0.24)	---	$0.2 ($0.17—$0.24)
School loss days	O_3	$0.01 ($0.004—$0.013)	---	$0.01 ($0.004—$0.013)
Minor restricted-activity	$PM_{2.5}$ & O_3	$0.7	---	$0.7

days		($0.3—$1)		($0.3—$1)
Recreational visibility, Class I areas	$PM_{2.5}$			$4.1
Social cost of carbon (3% discount rate, 2014 value)	CO_2			$0.6

Monetized total Benefits (Pope et al. 2002 $PM_{2.5}$ mortality and Bell et al. 2004 ozone mortality estimates)				
3% discount rate	$PM_{2.5}$, O_3	**$110 ($8.8—$340)**	**$0.28 ($0.01—$0.9)**	**$120 ($14—$350)**
7% discount rate	$PM_{2.5}$, O_3	**$100 ($8—$310)**	**$0.03 ($0.01—$0.85)**	**$110 ($13—$320)**
Monetized total Benefits (Laden et al. 2006 $PM_{2.5}$ mortality and Levy et al. 2005 ozone mortality estimates)				
3% discount rate	$PM_{2.5}$, O_3	**$270 ($24—$800)**	**$0.7 ($0.05—$2.1)**	**$280 ($29—$810)**
7% discount rate	$PM_{2.5}$, O_3	**$250 ($22—$720)**	**$0.6 ($0.04—$1.9)**	**$250 ($26—$730)**

[A] Estimates rounded to two significant figures.
[B] States included in transport region may be found in chapter 2.
[C] Monetary value of endpoints marked with dashes are < $100,000. [D] The negative estimates for certain endpoints are the result of the weak statistical power of the study used to calculate these health impacts and do not suggest that increases in air pollution exposure result in decreased health impacts.

1.1.2 Welfare Benefits

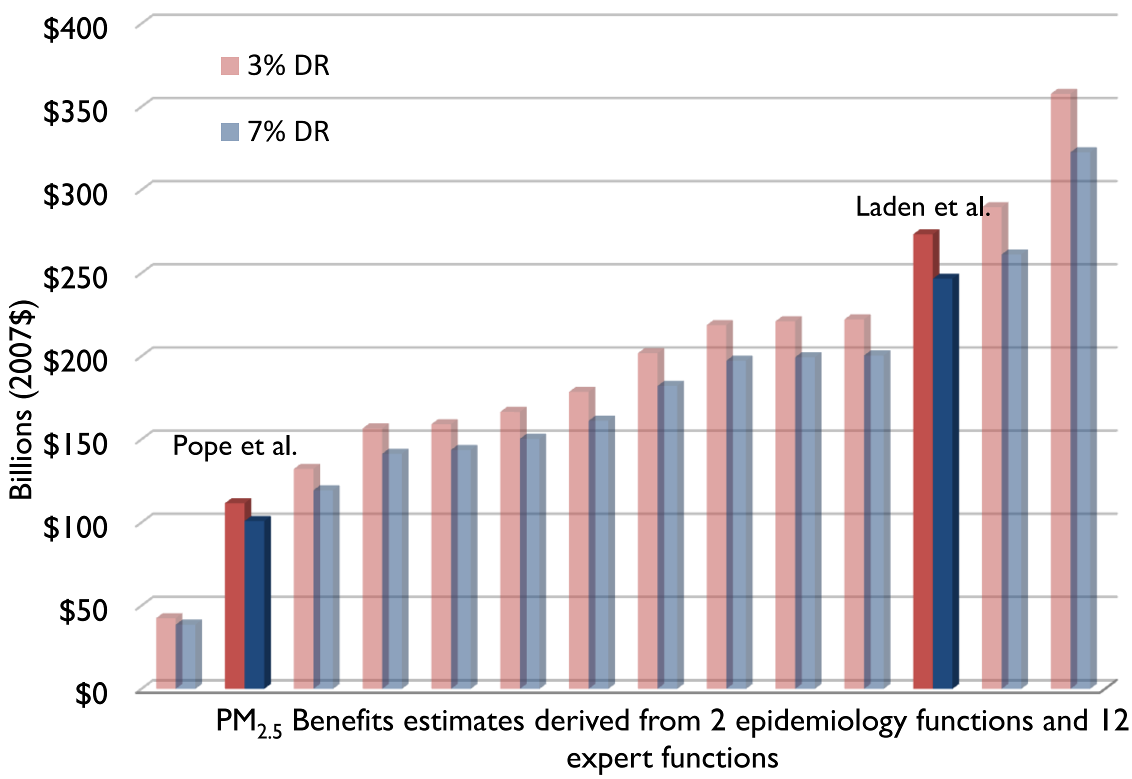
The term *welfare benefits* covers both environmental and societal benefits of reducing pollution, such as reductions in damage to ecosystems, improved visibility and improvements in recreational and commercial fishing, agricultural yields, and forest productivity. Although we are unable to monetize all welfare benefits, EPA estimates the final Transport Rule will yield welfare benefits of $4.1 billion in 2014 (2007$) for visibility improvements in southeastern Class I (national park) areas for a total of $4.1 billion in benefits across southeastern, southwestern and California Class I areas. These benefits are included in the full suite of benefits categories that are accounted for in the monetized benefits for this final rule.

Figure 1-1 summarizes an array of $PM_{2.5}$-related monetized benefits estimates based on alternative epidemiology and expert-derived PM-mortality estimate as well as the sum of ozone-related benefits using the Bell et al. (2004) mortality estimate.

Figure 1-2 summarizes the estimated net benefits for the selected remedy by displaying all possible combinations of PM and ozone-related monetized benefits and costs. The graphic includes one estimate of ozone-related mortality and fourteen different $PM_{2.5}$ related mortality and a single 3% or 7% discounted cost estimate.[2] Each of the 14 bars in each graph represents a separate point estimate of net benefits under a certain combination of cost and benefit estimation methods. Because it is not a distribution, it is not possible to infer the likelihood of any single net benefit estimate.

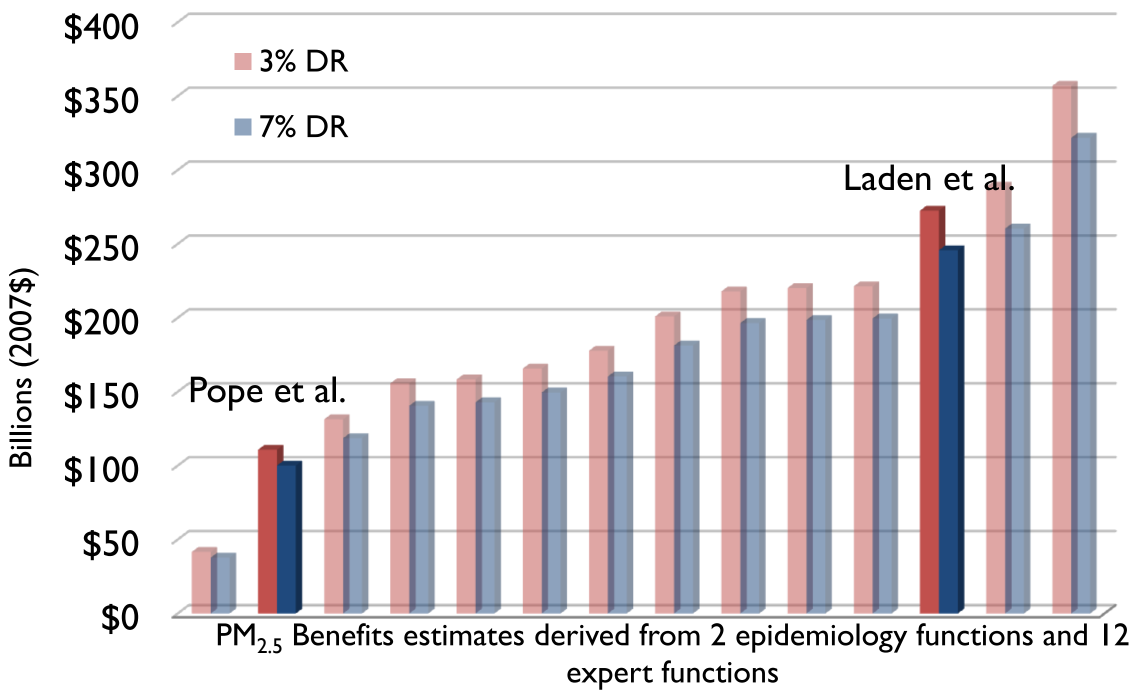
[2] Versions of this figure found in previous EPA RIA's have included the full suite of ozone mortality estimates. Because total benefits are relatively insensitive to the specification of ozone mortality estimate, for simplicity of presentation we have not included this full suite.

Figure 1-1 Estimated Monetized Value of Estimated $PM_{2.5}$- Related Premature Mortalities Avoided According to Epidemiology or Expert-derived Derived PM Mortality Risk Estimate[A]



[A] Column total equals sum of $PM_{2.5}$-related mortality and morbidity benefits and ozone-related morbidity and mortality benefits using the Bell et al. (2004) mortality estimate.

Figure 1-2: Net Benefits of the Transport Rule According to $PM_{2.5}$ Epidemiology or Expert-derived Mortality Risk Estimate[A]



[A] Column total equals sum of $PM_{2.5}$-related mortality and morbidity benefits and ozone-related morbidity and mortality benefits using the Bell et al. (2004) mortality estimate.

1.1.3 Assessment of More and Less Stringent Scenarios

1.1.3.1 Alternatives that Are More or Less Stringent

In accordance with Circular A-4 and EPA's for Guidelines for Preparing Economic Analyses, EPA also analyzed the costs and benefits of two options that differed in their stringency from the selected remedy option – one less stringent, the other more stringent. Both options have the same 2012 requirements and varied in the requirements for SO_2

emissions reductions in 2014. Both options only applied to the Group 1 states; requirements for SO_2 reductions remain the same in Group 2 states in 2014 under each option. Annual and ozone season NOx emissions requirements remain unchanged under these emission caps.

Unlike the selected remedy, which requires greater SO_2 reductions, reductions of up to $2,300/ton in marginal cost in 16 states (Group 1) beginning in 2014 from 2012 emissions levels, the less stringent option only requires SO_2 reductions in 2014 of up to $1,600/ton in marginal cost in Group 1 states. The more stringent option requires SO_2 reductions in 2014 of up to $10,000/ton in marginal cost in Group 1 states.

Table 1-4 provides a summary of the benefits, costs, and net benefits for the two alternatives considered to the selected remedy along with those for the selected remedy.

Table 1-4. Summary of Annual Benefits, Costs, and Net Benefits of Versions of the Selected Remedy Option in 2014[a] (billions of 2007 dollars)

Description	*Preferred Remedy*	*Less Stringent Scenario*	*More Stringent Scenario*
Social costs[b]			
3 % discount rate	$0.81	$0.43	$3.6
7 % discount rate	$0.81	$0.43	$3.6
Health-related benefits[c,d]			
3 % discount rate	$110 to $270 + B	$98 to $240 + B	$130 to $320 + B
7 % discount rate	$100 to $250 + B	$89 to $220 + B	$120 to $290 + B
Net benefits (benefits-costs)[e]			
3 % discount rate	$110 to $270	$98 to $240 + B	$130 to $320 + B
7 % discount rate	$100 to $250	$88 to $220 + B	$120 to $290 + B

[a] When presenting benefits and net benefits, EPA traditionally rounds all estimates to two significant figures. In this case we have rounded to three significant digits to facilitate comparison of the benefits and costs among the preferred remedy and the less and more stringent scenarios.

[b] The social costs are estimated using the MultiMarket model, the model employed by EPA in this RIA to estimate economic impacts of industries outside the electric power sector. This model does not estimate indirect impacts associated with a regulation such as this one. More information on the social costs can be found in Chapter 8 and Appendix B of this RIA.

[c] Due to methodological limitations, the health benefits of the two A-4 alternative remedies include $PM_{2.5}$ –related benefits but omit visibility, ozone, and CO_2-related benefits. We present the $PM_{2.5}$ –related benefits of the selected remedy, omitting these other important benefits, so that readers may compare directly the benefits of the selected and alternate remedies. Total benefits are primarily of the value of PM-related avoided premature mortalities. The reduction in these premature mortalities in each year account for over 90 percent of total $PM_{2.5}$ –related monetized benefits. Benefits in this table are nationwide and are associated with NO_x and SO_2 reductions. Visibility and ozone-related benefits not calculated for the more and less stringent scenarios because these impacts were estimated using $PM_{2.5}$-related benefit per ton estimates.

[d] Not all possible benefits or disbenefits are monetized in this analysis. These are listed in Table 1-5.

[e] Valuation assumes discounting over the SAB-recommended 20-year segmented lag structure. Results reflect the use of 3 % and 7 % discount rates consistent with EPA and OMB guidelines.

1.2 Not All Benefits Quantified

EPA was unable to quantify or monetize all of the health and environmental benefits associated with the Transport Rule. EPA believes these unquantified benefits are substantial, including the value of increased agricultural crop and commercial forest yields, visibility improvements, reductions in nitrogen and acid deposition and the resulting changes in ecosystem functions, and health and welfare benefits associated with reduced mercury emissions. Table 1-5 provides a list of these benefits.

Table 1-5: Human Health and Welfare Effects of Pollutants Affected by the Transport Rule

Pollutant/ Effect	*Quantified and monetized in base estimate*	*Unquantified*
PM: health[a]	Premature mortality based on cohort study estimates[b] Premature mortality based on expert elicitation estimates Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarctions) Lower and upper respiratory illness Minor restricted activity days **Work loss days** Asthma exacerbations (among asthmatic populations Respiratory symptoms (among asthmatic populations) Infant mortality	Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits UVb exposure (+/-)[c]
PM: welfare	Visibility in Class I areas	Household soiling Visibility in residential and non-class I areas UVb exposure (+/-)[c] Global climate impacts[c]
Ozone: health	Premature mortality based on short-term study estimates Hospital admissions: respiratory Emergency room visits for asthma Minor restricted activity days School loss days	Chronic respiratory damage Premature aging of the lungs Non-asthma respiratory emergency room visits UVb exposure (+/-)[c]
Ozone: welfare	Decreased outdoor worker productivity	Yields for: --Commercial forests --Fruits and vegetables, and --Other commercial and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest

	aesthetics Ecosystem functions UVb exposure (+/-)[c]
NO_2: health	Respiratory hospital admissions Respiratory emergency department visits Asthma exacerbation Acute respiratory symptoms Premature mortality Pulmonary function
NO_2: welfare	Commercial fishing and forestry from acidic deposition Commercial fishing, agriculture and forestry from nutrient deposition Recreation in terrestrial and estuarine ecosystems from nutrient deposition Other ecosystem services and existence values for currently healthy ecosystems Coastal eutrophication from nitrogen deposition
SO_2: health	Respiratory hospital admissions Asthma emergency room visits Asthma exacerbation Acute respiratory symptoms Premature mortality Pulmonary function
SO_2: welfare	Commercial fishing and forestry from acidic deposition Recreation in terrestrial and aquatic ecosystems from acid deposition Increased mercury methylation
Mercury: health	Incidence of neurological disorders Incidence of learning disabilities Incidences in developmental delays Potential cardiovascular effects including: --Altered blood pressure regulation --Increased heart rate variability --Incidences of heart attack Potential reproductive effects
Mercury: environment	Impact on birds and mammals (e.g. reproductive effects)
Mercury: welfare	Impacts to commercial., subsistence and recreational fishing

[a] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[b] Cohort estimates are designed to examine the effects of long term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter term exposures (see Kunzli et al., 2001 for a discussion of this issue). While some of the effects of short term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short term PM exposure not captured in the cohort estimates included in the primary analysis.

[c] May result in benefits or disbenefits.

1.3 Costs and Economic Impacts

For the affected region, the projected annual incremental private costs of the selected remedy option (air quality-assured trading) to the power industry are $1.4 billion in 2012 and $0.8 billion in 2014 (in 2007 dollars). Costs are lower in 2014 than in 2012 as the rule becomes more stringent because there are larger amounts of State and Federally enforceable controls that happen between 2012 and 2014 in the baseline. These costs represent the total cost to the electricity-generating industry of reducing NO_x and SO_2 emissions to meet the emissions caps set out in the rule. Estimates are in 2007 dollars. These costs of the rule are estimated using the Integrated Planning Model (IPM). It should be noted that the rule modeled for this analysis differs from the final rule in that it includes reductions that would be required by the supplemental proposal for six states (Iowa, Kansas, Michigan, Missouri, Oklahoma, and Wisconsin). These reductions are included in the cost and impacts estimates described in this RIA, and therefore are accounted for in the benefits estimates.

In estimating the net benefits of regulation presented above, the appropriate cost measure is "social costs." Social costs represent the changes in social welfare from the rule measured as the change in total surplus (consumer and producer) in the macroeconomic analysis of this rule.

There are several national changes in energy prices that result from the Transport Rule. Retail electricity prices are projected to increase nationally by an average of 1.3 % in 2012 and 0.8 % in 2014 with the final Transport Rule. The average delivered coal price decreases by about 1.4 percent in 2012 and 0.5 percent in 2014 relative to the base case as a result of decreased coal demand and shifts in the type of coal demanded. EPA also projects that delivered natural gas prices for the electric power sector will increase by about 0.3% over the 2012-2030 timeframe and that natural gas use for electricity generation will increase by approximately 200 billion cubic feet (BCF) by 2014, or roughly 4%. This impact is well within the range of price variability that is regularly experienced in natural gas markets. Finally, under the Transport Rule, EPA projects coal production for use by the power sector will increase above 2009 levels by 40 million tons in 2012 and 54 million tons in 2014 (compared to roughly one billion tons of total coal produced for the power sector in 2009). This increase in production is 16% less in 2012 and 27% less in 2014 than the increase projected in the base case. The Transport Rule is not projected to impact production of coal for uses outside the power sector (e.g., export, industrial sources), which represent approximately 6% of total coal production in 2009. More detail and background for these results can be found in Chapter 7 of the RIA.

There are several other types of energy impacts from the Transport Rule. A relatively small amount of coal-fired capacity, about 4.8 GW (1 percent of all coal-fired capacity and 0.5% of total generating capacity), is projected to be uneconomic to maintain and EPA forecast that 1 GW of that capacity was likely to be unprofitable to operate in the 2020 in the base case. In practice units projected to be uneconomic to maintain may be "mothballed," retired, or kept in service to ensure transmission reliability in certain parts of the grid. For the most part, these units are small and infrequently used generating units that are dispersed throughout the Transport Rule region.

In addition to addressing the costs, benefits, and economic impacts of the Transport Rule, EPA has estimated a portion of the employment impacts of this rulemaking. We have estimated three types of impacts. One provides an estimate of the employment impacts on the regulated industry over time. The second covers the short-term employment impacts associated with the construction of needed pollution control equipment until the compliance date of the regulation. The third is to estimate short-term employment impacts extending outside of the power sector, as described in Appendix D. We expect that the rule's impact on employment will be small.

In Table 1-6, we show the employment impacts of the Transport Rule as estimated by the environmental protection sector approach and by the Morgenstern approach. The estimated employment changes due to changes in fuel use are reported in Chapter 8.

Table 1-6. Estimated Employment Impact Table

	Annual (reoccurring)	**One time (construction during compliance period)**
Environmental Protection Sector approach*	Not Applicable	2,230
Net Effect on Electric Utility Sector Employment from Morgenstern et al. approach***	700** -1, 000 to +3,000****	Not Applicable

*These one-time impacts on employment are estimated in terms of job-years.

**This estimate is not statistically different from zero.

**These annual or reoccurring employment impacts are estimated in terms of production workers as defined by the US Census Bureau's Annual Survey of Manufacturers (ASM).

**** 95% confidence interval

Overall, the impacts of the final rule are modest, particularly in light of the large projected benefits mentioned earlier.

1.4 Small Entity and Unfunded Mandates Impacts

After preparing an analysis of small entity impacts, EPA has certified that this final rule will have no SISNOSE (significant economic impacts on a substantial number of small entities). First, of the small entities projected to have costs greater than 1 percent of revenues (24 out of 108 affected), around 70 percent of them operate in cost of service regions and would generally be able to pass any increased costs along to rate-payers. In EPA's modeling, most of the cost impacts for these small entities and their associated units are driven by lower electricity generation relative to the base case. Specifically, two units reduce their generation by significant amounts, driving the bulk of the costs for all small entities. Excluding these two units, another driver of small entity impacts for sub-divisions and private small entities is higher fuel costs, which the affected units would be expected to use irrespective of whether they had to comply with this rule. Further, increased fuel costs are often passed through to rate-payers as common practice in many areas of the U.S. due to fuel adder arrangements instituted by state public utility commissions. Finally, EPA's decision to exclude units smaller than 25 Megawatt capacity (MW) has already significantly reduced the burden on small entities by reducing the number of affected small entity-owned units by about 390.

EPA examined the potential economic impacts on state and municipality-owned entities associated with this rulemaking based on assumptions of how the affected states will implement control measures to meet their emissions. These impacts have been calculated to provide additional understanding of the nature of potential impacts and additional information.

According to EPA's analysis, of the 98 government entities considered in this analysis and the 365 government entities in the Transport Rule region that are included in EPA's modeling, 26 may experience compliance costs in excess of 1 percent of revenues in 2014, based on our assumptions of how the affected states implement control measures to meet their emissions budgets as set forth in this rulemaking.

Government entities projected to experience compliance costs in excess of 1 percent of revenues may have some potential for significant impact resulting from implementation of the Transport Rule. However, it is EPA's position that because these government entities can pass on their costs of compliance to rate-payers, they will not be significantly affected. Furthermore, the decision to include only units greater than 25 MW in size exempts 354 government entities that would otherwise be potentially affected by the Transport Rule.

1.5 Limitations and Uncertainties

Every analysis examining the potential benefits and costs of a change in environmental protection requirements is limited to some extent by data gaps, limitations in model capabilities (such as geographic coverage), and variability or uncertainties in the underlying scientific and economic studies used to configure the benefit and cost models. Despite the uncertainties, we believe this benefit-cost analysis provides a reasonable indication of the expected economic benefits and costs of the final Transport Rule.

For this analysis, such uncertainties include possible errors in measurement and projection for variables such as population growth and baseline incidence rates; uncertainties associated with estimates of future-year emissions inventories and air quality; variability in the estimated relationships between changes in pollutant concentrations and the resulting changes in health and welfare effects; and uncertainties in exposure estimation.

EPA's cost estimates assume that all states in the final Transport Rule region participate in the programs that reduce SO_2 and NO_x emissions from the power industry, rather than complying with state-level requirements through other regulatory means.

Below is a summary of the key uncertainties of the analysis:

Costs

- Analysis does not capture employment shifts as workers are retrained at the same company or re-employed elsewhere in the economy.

- We do not include the costs of certain relatively small permitting costs associated with Title V that new program entrants face.
- Technological innovation is not incorporated into these cost estimates.
- Economic impacts do not take into response of electric power consumers to changes in electricity prices. While this response is likely to be of small magnitude, it may have some impact on the final estimate of private compliance costs.

Benefits

- Most of the estimated PM-related benefits in this rule accrue to populations exposed to higher levels of $PM_{2.5}$. Of these estimated PM-related mortalities avoided, about 69% occur among populations initially exposed to annual mean $PM_{2.5}$ level of 10 $\mu g/m^3$ and about 96% occur among those initially exposed to annual mean $PM_{2.5}$ level of 7.5 $\mu g/m^3$; these are the lowest air quality levels considered in the Laden et al. (2006) and Pope et al. (2002) studies, respectively. This fact is important, because as we estimate PM-related mortality among populations exposed to levels of $PM_{2.5}$ that are successively lower, our confidence in the results diminishes. However, our analysis shows that the great majority of the impacts occur at higher exposures.

- There are uncertainties related to the health impact functions used in the analysis. These include: within study variability; across study variation; the application of concentration-response (C-R) functions nationwide; extrapolation of impact functions across population; and various uncertainties in the C-R function, including causality and thresholds. Therefore, benefits may be under- or over-estimates.

- Analysis is for 2014, and projecting key variables introduces uncertainty. Inherent in any analysis of future regulatory programs are uncertainties in projecting atmospheric conditions and source level emissions, as well as population, health baselines, incomes, technology, and other factors.

- This analysis omits certain unquantified effects due to lack of data, time and resources. These unquantified endpoints include other health and ecosystem effects. EPA will continue to evaluate new methods and models and select those most appropriate for estimating the benefits of reductions in air pollution. Enhanced collaboration between air quality modelers, epidemiologists, toxicologists, ecologists, and economists should result in a more tightly integrated analytical framework for measuring benefits of air pollution policies.

- $PM_{2.5}$ mortality benefits represent a substantial proportion of total monetized benefits (over 90%), and these estimates have following key assumptions and uncertainties.

    1. The $PM_{2.5}$ -related benefits of the alternative scenarios were derived through a benefit per-ton approach, which does not fully reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an over-estimate or under-estimate of the actual benefits of controlling SO_2.

    2. We assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from EGUs may differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources, but no clear scientific grounds exist for supporting differential effects estimates by particle type.

    3. We assume that the health impact function for fine particles is linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5,}$ including both regions that are in attainment with fine particle standard and those that do not meet the standard down to the lowest modeled concentrations.

    4. To characterize the uncertainty in the relationship between $PM_{2.5}$ and premature mortality, we include a set of twelve estimates based on results of the expert elicitation study in addition to our core estimates. Even these multiple characterizations omit the uncertainty in air quality estimates, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the $PM_{2.5}$ estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

These projected impacts of this final rule do not reflect minor technical corrections to SO2 budgets in three states (KY, MI, and NY). These projections also assumed preliminary variability limits that were smaller than the variability limits finalized in this rule. EPA conducted sensitivity analysis confirming that these differences do not meaningfully alter any of the Agency's findings or conclusions based on the projected cost, benefit, and air quality impacts presented for the final Transport Rule. The results of this sensitivity analysis are presented in Appendix F in the final Transport Rule RIA.

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Chapter 5

Benefits Analysis and Results

Synopsis

This chapter contains a subset of the estimated health and welfare benefits of the Transport Rule remedy in 2014. This rule is expected to yield significant reductions in SO_2 and NO_x from EGUs, which in turn would lower overall ambient levels of $PM_{2.5}$ and ozone across much of the eastern U.S. In this chapter we quantify the health and welfare benefits resulting from these air quality improvements.

We estimate the monetized benefits of the selected remedy to be $120 billion to $280 billion at a 3% discount rate and $110 billion to $250 billion at a 7% discount rate in 2014. The benefits of the more and less stringent alternatives may be found in the benefit-cost comparison chapter. All estimates are in 2007$. We estimate the benefits of the selected remedy using modeled changes in ambient pollution concentrations while the benefits of the more and less stringent remedies are based on a benefit per ton approach described below. This benefits analysis accounts for both decreases and increases in emissions across the country. These estimates omit the benefits from several important categories, including ecosystem benefits, mercury benefits, and the direct health benefits from reducing exposure to NO_2 and SO_2 due to time constraints.

The estimated benefits of this rule are substantial, particularly when viewed within the context of the total public health burden of $PM_{2.5}$ and ozone air pollution. A recent EPA analysis estimated that 2005 levels of $PM_{2.5}$ and ozone were responsible for between 130,000 and 320,000 $PM_{2.5}$-related and 4,700 ozone-related premature deaths, or about 6.1% of total deaths from all causes in the continental U.S. (Fann et al. 2011). This same analysis attributed almost 200,000 non-fatal heart attacks, 90,000 hospital admissions due to respiratory or cardiovascular illness and 2.5 million cases of aggravated asthma among children--among many other impacts. We estimate the Transport Rule to reduce the number of $PM_{2.5}$-related premature deaths in 2014 by between 13,000 and 34,000, 15,000 non-fatal heart attacks, 8,700 fewer hospital admissions and 400,000 fewer cases of aggravated asthma. By 2014, in combination with other federal and state air quality actions, the Transport Rule will address a substantial fraction of the total public health burden of $PM_{2.5}$ and ozone air pollution.

EPA expects greater emission reductions due to this rule in 2012 than in 2014, due to substantial emission reductions expected to occur in the baseline (i.e., unrelated to the Transport Rule) between those years. As a result, we anticipate that the avoided health impacts and monetized benefits would also be greater in 2012, though we have not calculated these estimates for this analysis.

Appendix A to this RIA contains an assessment of the distribution of health benefits among different populations. In this analysis, we considered the level of $PM_{2.5}$ mortality risk according to the race, income and educational attainment of the population before and after the implementation of the Transport Rule. We found those populations whose $PM_{2.5}$ mortality risk was before the implementation of the rule received the greatest risk reduction from the Transport Rule—irrespective of the race of the population. We also found that populations with lower levels of educational attainment, an attribute that may be associated with increased vulnerability to PM2.5 mortality risk, also received a significant reduction in risk.

Finally, Appendix E provides an alternate presentation of the benefits as an attempt to incorporate the recommendations from EPA's recently published Guidelines for Preparing Economic Analyses (U.S. EPA, 2010).

5.1 Overview

This chapter contains a subset of the estimated health and welfare benefits of the selected and alternate rule remedies for the Transport Rule in 2014. The Transport Rule is expected to yield significant aggregate reductions in SO_2 and NO_x from EGUs, which in turn would lower overall ambient levels of $PM_{2.5}$ and ozone across much of the eastern U.S. To perform this analysis, EPA followed an approach that is generally consistent with the proposal Transport Rule analysis, with the exception of the baseline incidence rates that are an input into the health impact calculation for $PM_{2.5}$ and ozone health outcomes. These updated rates are both more current and provide better spatial resolution in many areas of the U.S. As we describe in section 5.4 below, these updated data are likely to yield a better overall estimate of PM and ozone-related health impacts.

The analysis in this chapter aims to characterize the benefits of the selected remedy by answering two key questions:

1. What are the health and welfare effects of changes in ambient particulate matter ($PM_{2.5}$) and ozone air quality resulting from reductions in precursors including NO_x and SO_2?
2. What is the economic value of these effects?

In this analysis we consider an array of health and welfare impacts attributable to changes in $PM_{2.5}$ and ozone air quality. The 2009 $PM_{2.5}$ Integrated Science Assessment (U.S. EPA, 2009d) and the 2006 ozone criteria document (U.S. EPA, 2006a) identify the human health effects associated with these ambient pollutants, which include premature mortality and a variety of morbidity effects associated with acute and chronic exposures. PM welfare effects include visibility impairment and materials damage. Ozone welfare effects include damages to agricultural and forestry sectors. NO_x welfare effects include aquatic and terrestrial acidification and nutrient enrichment (U.S. EPA, 2008f). SO_2 welfare effects include aquatic and terrestrial acidification and increased mercury methylation (U.S. EPA, 2008f). Though models exist for quantifying these ecosystem impacts, time and resource constraints precluded us from quantifying most of those effects in this analysis.

Table 5-1 summarizes the total monetized benefits of the final Transport Rule remedy in 2014. This table reflects the economic value of the change in $PM_{2.5}$ and ozone-related human health impacts occurring as a result of the Transport Rule.

Table 5-2 summarizes the human health and welfare benefits categories contained within the primary benefits estimate, those categories that were unquantified due to limited data or time.

Table 5-1: Estimated monetized benefits of the final Transport Rule remedy (billions of 2007$)[A]

Benefits Estimate	*Within Transport Region[B]*	*Outside Transport Region*	*Total*
Pope et al. (2002) $PM_{2.5}$ mortality and Bell et al. (2004) ozone mortality estimates			
Using a 3% discount rate	$110 +B ($8.8—$340)	$0.28 +B ($0.01—$0.9)	$120 +B ($14—$350)
Using a 7% discount rate	$100 +B ($8—$310)	$0.25 +B ($0.01—$0.85)	$110 +B ($13—$320)
Laden et al. (2006) $PM_{2.5}$ mortality and Levy et al. (2005) ozone mortality estimates			
Using a 3% discount rate	$270 +B ($24—$800)	$0.7 +B ($0.05—$0.21)	$280 +B ($29—$810)
Using a 7% discount rate	$250 +B ($22—$720)	$0.6 +B ($0.04—$1.9)	$250 +B ($26—$730)

[A] For notational purposes, unquantified benefits are indicated with a "B" to represent the sum of additional monetary benefits and disbenefits. Data limitations prevented us from quantifying these endpoints, and as such, these benefits are inherently more uncertain than those benefits that we were able to quantify. A detailed listing of unquantified health and welfare effects is provided in Table 5-2. Estimates here are subject to uncertainties discussed further in the body of the document. Estimates include the value of CO_2-related benefits and the monetized benefits of visibility improvements in Class I areas.

[B] Rounded to two significant figures.

The benefits analysis in this chapter relies on an array of data inputs—including air quality modeling, health impact functions and valuation estimates among others—which are themselves subject to uncertainty and may also in turn contribute to the overall uncertainty in this analysis. As a means of characterizing this uncertainty we employ two primary techniques. First, we use Monte Carlo methods for characterizing random sampling error associated with the concentration response functions from epidemiological studies and economic valuation functions. Second, because this characterization of random statistical error may omit important sources of uncertainty we also employ the results of an expert elicitation on the relationship between premature mortality and ambient $PM_{2.5}$ concentration (Roman et al., 2008); this provides additional insight into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. Both approaches have different strengths and weaknesses, which are fully described in Chapter 5 of the PM NAAQS RIA (U.S. EPA, 2006).

Given that reductions in premature mortality dominate the size of the overall monetized benefits, more focus on uncertainty in mortality-related benefits gives us greater confidence in our uncertainty characterization surrounding total benefits. Certain EPA RIA's including the 2008 Ozone NAAQS RIA (U.S. EPA, 2008a) contained a suite of sensitivity analyses, only some of which we include here due in part to time constraints. In particular, these analyses characterized the sensitivity of the monetized benefits to the specification of alternate cessation lags and income growth adjustment factors. The estimated benefits increased or decreased in proportion to the specification of alternate income growth adjustments and cessation lags, making it possible for readers to infer the sensitivity of the results in this RIA to these parameters by referring to the PM NAAQS RIA (2006d) and Ozone NAAQS RIA (2008a).

For example, the use of an alternate lag structure would change the $PM_{2.5}$-related mortality benefits discounted at 3% discounted by between 10.4% and –27%; when discounted at 7%, these benefits change by between 31% and -49%. When applying higher and lower income growth adjustments, the monetary value of $PM_{2.5}$ and ozone-related premature changes between 30% and -10%; the value of chronic endpoints change between 5% and -2% and the value of acute endpoints change between 6% and -7%.

Below we include a new analysis (Figures 5-19 and 5-20) in which we bin the estimated number of avoided $PM_{2.5}$-related premature mortalities resulting from the implementation of the Transport Rule according to the projected 2014 baseline $PM_{2.5}$ air quality levels. This presentation is consistent with our approach to applying $PM_{2.5}$ mortality risk coefficients that have not been adjusted to incorporate an assumed threshold. The very large proportion of the avoided PM-related impacts we estimate in this analysis occur among populations exposed at or above the LML of each study, increasing our confidence in the PM mortality analysis. Approximately 69% of the avoided impacts occur at or above an annual mean $PM_{2.5}$ level of 10 μg/m^3 (the LML of the Laden et al. 2006 study); about 96% occur at or above an annual mean $PM_{2.5}$ level of 7.5 μg/m^3 (the LML of the Pope et al. 2002 study). As we model mortality impacts among populations exposed to levels of $PM_{2.5}$ that are successively lower than the LML of each study our confidence in the results diminishes. However, the analysis below confirms that the great majority of the impacts occur at or above each study's LML.

Table 5-2: Human Health and Welfare Effects of Pollutants Affected by the Transport Rule

Pollutant/ Effect	*Quantified and monetized in base estimate*	*Unquantified*
PM: health[a]	Premature mortality based on cohort study estimates[b] and expert elicitation estimates Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarctions) Lower and upper respiratory illness Minor restricted activity days Work loss days Asthma exacerbations (among asthmatic populations) Respiratory symptoms (among asthmatic populations) Infant mortality	Low birth weight, pre-term birth and other reproductive outcomes Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits UVb exposure (+/-)[c]
PM: welfare	Visibility in Class I areas in SE, SW, and CA regions	Household soiling Visibility in residential areas Visibility in non-class I areas and class 1 areas in NW, NE, and Central regions UVb exposure (+/-)[c] Global climate impacts[c]
Ozone: health	Premature mortality based on short-term study estimates Hospital admissions: respiratory Emergency room visits for asthma Minor restricted activity days School loss days	Chronic respiratory damage Premature aging of the lungs Non-asthma respiratory emergency room visits UVb exposure (+/-)[c]
Ozone: welfare	Decreased outdoor worker productivity	Yields for: --Commercial forests --Fruits and vegetables, and --Other commercial and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-)[c] Climate impacts
NO_2: health		Respiratory hospital admissions Respiratory emergency department visits Asthma exacerbation Acute respiratory symptoms Premature mortality Pulmonary function
NO_X: welfare		Commercial fishing and forestry from acidic deposition effects Commercial fishing, agriculture and forestry from nutrient deposition effects Recreation in terrestrial and estuarine ecosystems from nutrient deposition effects Other ecosystem services and existence values for

	currently healthy ecosystems Coastal eutrophication from nitrogen deposition effects
SO_2: health	Respiratory hospital admissions Asthma emergency room visits Asthma exacerbation Acute respiratory symptoms Premature mortality Pulmonary function
SO_X: welfare	Commercial fishing and forestry from acidic deposition effects Recreation in terrestrial and aquatic ecosystems from acid deposition effects Increased mercury methylation
Mercury: health	Incidence of neurological disorders Incidence of learning disabilities Incidences in developmental delays
Mercury: welfare	Impact on birds and mammals (e.g. reproductive effects) Impacts to commercial, subsistence and recreational fishing

[A] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[B] Cohort estimates are designed to examine the effects of long term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter term exposures (see Kunzli et al., 2001 for a discussion of this issue). While some of the effects of short term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short term PM exposure not captured in the cohort estimates included in the primary analysis.

[C] May result in benefits or disbenefits.

5.2 Benefits Analysis Methods

We follow a "damage-function" approach in calculating total benefits of the modeled changes in environmental quality. This approach estimates changes in individual health and welfare endpoints (specific effects that can be associated with changes in air quality) and assigns values to those changes assuming independence of the individual values. Total benefits are calculated simply as the sum of the values for all non-overlapping health and welfare endpoints. The "damage-function" approach is the standard method for assessing costs and benefits of environmental quality programs and has been used in several recent published analyses (Levy et al., 2009; Hubbell et al., 2009; Tagaris et al., 2009).

To assess economic value in a damage-function framework, the changes in environmental quality must be translated into effects on people or on the things that people value. In some cases, the changes in environmental quality can be directly valued, as is the case for changes in visibility. In other cases, such as for changes in ozone and PM, a health and welfare impact analysis must first be conducted to convert air quality changes into effects that can be assigned dollar values.

For the purposes of this RIA, the health impacts analysis (HIA) is limited to those health effects that are directly linked to ambient levels of air pollution and specifically to those linked to ozone and PM. There may be other, indirect health impacts associated with implementing emissions controls, such as occupational health impacts for coal miners.

The welfare impacts analysis is limited to changes in the environment that have a direct impact on human welfare. For this analysis, we are limited by the available data to examine impacts of changes in visibility in Class 1 areas. We also provide qualitative discussions of the impact of changes in other environmental and ecological effects, for example, changes in deposition of nitrogen and sulfur to terrestrial and aquatic ecosystems, but we are unable to place an economic value on these changes due to time and resource limitations.

We note at the outset that EPA rarely has the time or resources to perform extensive new research to measure directly either the health outcomes or their values for regulatory analyses. Thus, similar to Kunzli et al. (2000) and other recent health impact analyses, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Adjustments are made for the level of environmental quality change, the socio-demographic and economic characteristics of the affected population, and other factors to improve the accuracy and robustness of benefits estimates.

5.2.1 Health Impact Assessment

The Health Impact Assessment (HIA) quantifies the changes in the incidence of adverse health impacts resulting from changes in human exposure to $PM_{2.5}$ and ozone air quality. HIAs are a well-established approach for estimating the retrospective or prospective change in adverse health impacts expected to result from population-level changes in exposure to pollutants (Levy et al. 2009). PC-based tools such as the environmental Benefits Mapping and Analysis Program (BenMAP) can systematize health impact analyses by applying a database of key input parameters, including health impact functions and population projections. Analysts have applied the HIA approach to estimate human health impacts resulting from hypothetical changes in pollutant levels (Hubbell et al. 2005; Davidson et al. 2007, Tagaris et al. 2009). EPA and others have relied upon this method to predict future changes in health impacts expected to result from the implementation of regulations affecting air quality (U.S. EPA, 2008a).

The HIA approach used in this analysis involves three basic steps: (1) utilizing CAMx-generated projections of $PM_{2.5}$ and ozone air quality and estimating the change in the spatial distribution of the ambient air quality; (2) determining the subsequent change in population-level exposure; (3) calculating health impacts by applying concentration-response relationships drawn from the epidemiological literature (Hubbell et al. 2009) to this change in population exposure.

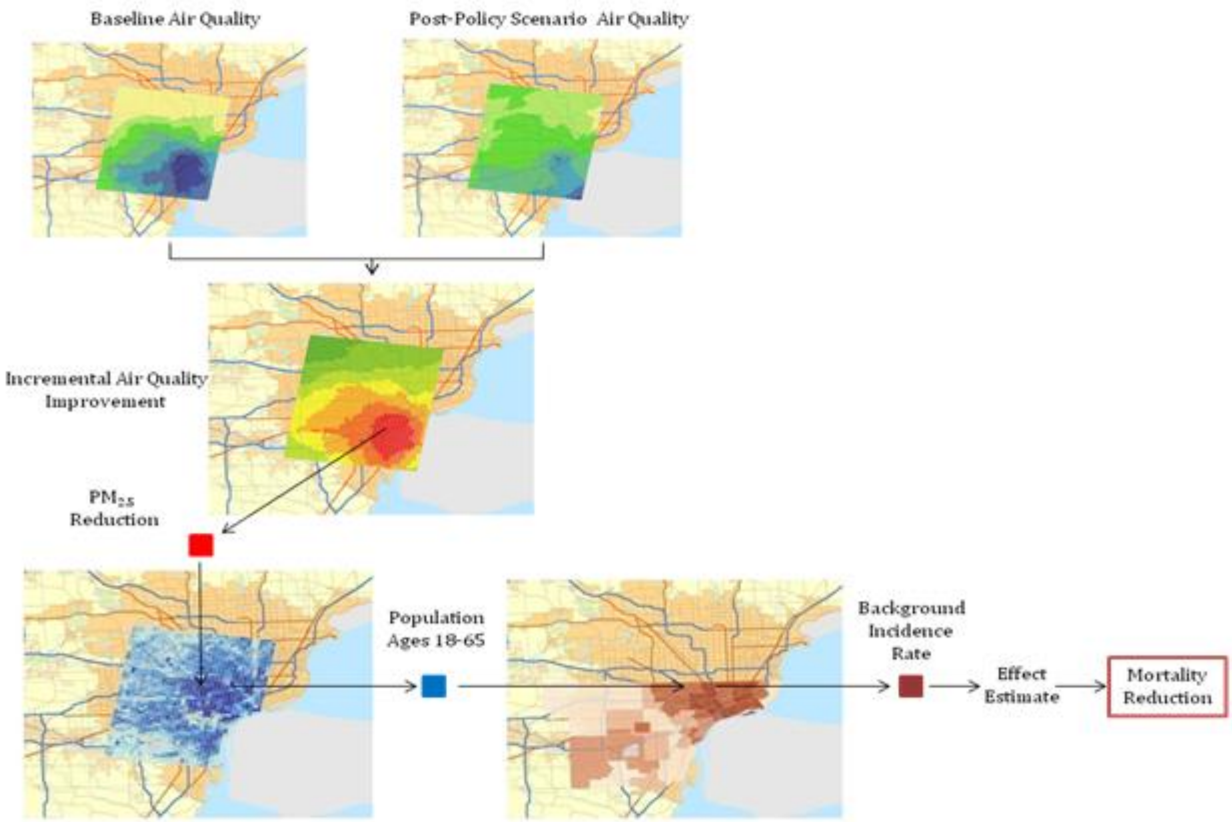
A typical health impact function might look as follows:

$$\Delta y = y_o \cdot \left(e^{\beta \cdot \Delta x} - 1\right) \cdot Pop$$

where y_0 is the baseline incidence rate for the health endpoint being quantified (for example, a health impact function quantifying changes in mortality would use the baseline, or background, mortality rate for the given population of interest); *Pop* is the population affected by the change in air quality; Δx is the change in air quality; and β is the effect coefficient drawn from the epidemiological study. Tools such as BenMAP can systematize the HIA calculation process, allowing users to draw upon a library of existing air quality monitoring data, population data and health impact functions.

Figure 5-1 provides a simplified overview of this approach.

Figure 5-1: Illustration of BenMAP Approach



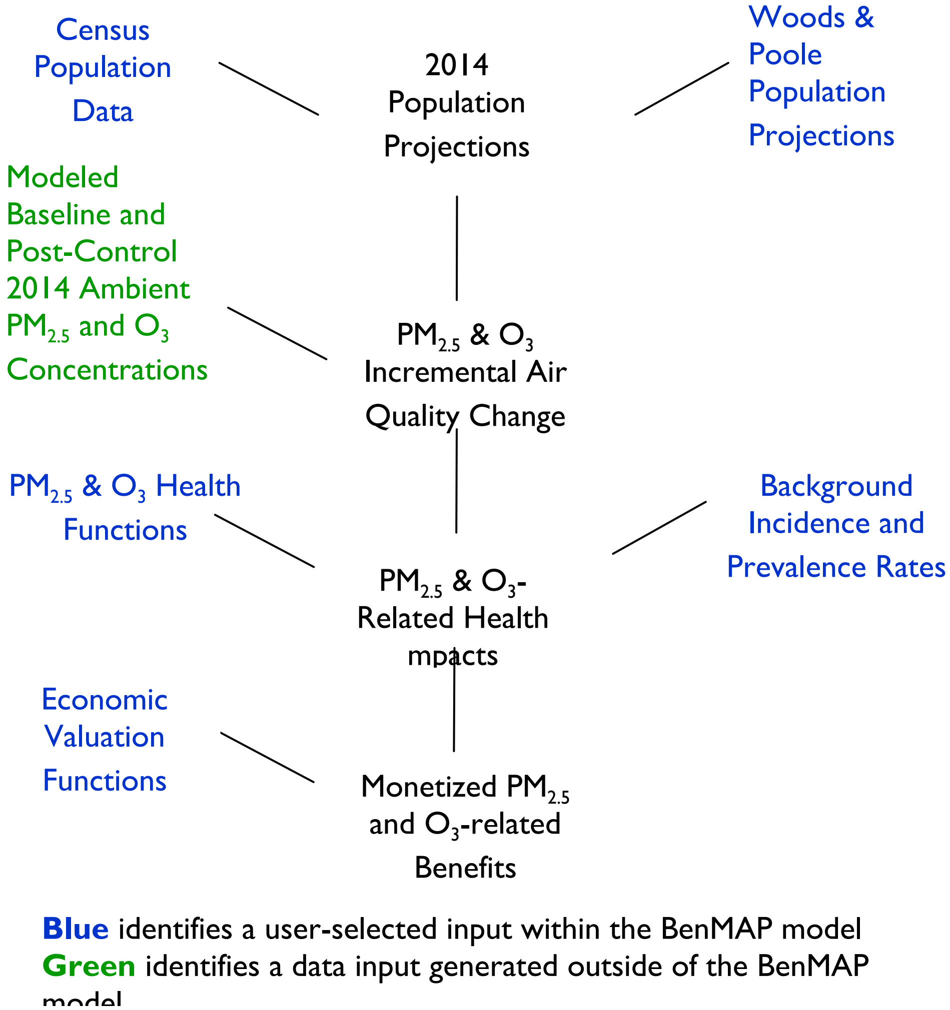
5.2.2 Economic Valuation of Health Impacts

After quantifying the change in adverse health impacts, the final step is to estimate the economic value of these avoided impacts. The appropriate economic value for 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 effects by a small amount for a large population. The appropriate economic measure is therefore *ex ante* Willingness to Pay (WTP) for changes in risk. However, epidemiological studies generally provide estimates of the relative risks 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 a primary 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 cost of illness (COI) estimates generally (although not in every case) understate the true value of reductions in risk of 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.

We use the BenMAP model (Abt Associates, 2008) to estimate the health impacts and monetized health benefits for the preferred remedy. Figure 5-2 below shows the data inputs and outputs for the BenMAP model.

Figure 5-2: Data inputs and outputs for the BenMAP model



5.2.3 Benefit Per-Ton Estimates

Benefit per-ton (BPT) estimates quantify the health impacts and monetized human health benefits of an incremental change in air pollution precursor emissions. In situations when we are unable to perform air quality modeling because of resource or time constraints, this approach can provide a reliable estimate of the benefits of emission reduction scenarios. EPA has used the benefit per-ton technique in previous RIAs, including the recent Ozone NAAQS RIA (U.S. EPA, 2008) and NO_2 NAAQS RIA (U.S. EPA, 2010b). Time constraints prevented the Agency from modeling the air quality changes resulting from e the more and less stringent SO_2 caps and so we estimate a subset of these health benefits using $PM_{2.5}$ benefit per-ton estimates. The assessment of the alternate scenarios omits ozone-related benefits for two reasons. First, the overall level of ozone-related benefits in the modeled case is relatively small compared to those associated with $PM_{2.5}$ reductions (see table 5-17 below), due in part to the fairly modest summer time NO_x

emission reductions under this scenario. The level of summertime NO_x emission reductions of the alternate scenarios are very similar to the modeled scenario, suggesting that the omission of ozone-related impacts would not greatly influence the overall level of benefits. Second, the complex non-linear chemistry of ozone formation introduces uncertainty to the development and application of a benefit per ton estimate. Taken together, these factors argued against developing an ozone benefit per ton estimate for this RIA.

For this analysis, EPA applies $PM_{2.5}$ BPT estimates that are methodologically consistent with those reported in Fann et al. (2009), but have been adjusted for this analysis to better match the spatial distribution of air quality changes projected for the Transport Rule. To derive the BPT estimates for this analysis, we:

1. *Quantified the $PM_{2.5}$-related human and monetized health benefits of the SO_2 emission reductions of the proposed remedy*. We first quantified the health impacts and monetized benefits of total $PM_{2.5}$ mass formed from the SO_2 reductions of the proposed remedy, allowing us to isolate the PM air quality impacts from SO_2 reductions alone.[20] This procedure allowed us to develop $PM_{2.5}$ BPT estimates that quantified the $PM_{2.5}$-related benefits of incremental changes in SO_2 emissions. Because reductions in NO_x emissions are relatively small in each scenario, and previous EPA modeling indicates that $PM_{2.5}$ formation is less sensitive to NO_x emission reductions on a per-$\mu g/m^3$ basis (Fann et al, 2009), we did not quantify the NO_x-related $PM_{2.5}$ changes.

2. *Divided the health impacts and monetized benefits by the emission reduction.* This calculation yields BPT estimates for PM-related SO_2.

The resulting BPT estimates were then multiplied by the projected SO_2 emission reductions for the more and less stringent scenarios to produce an estimate of the PM- and ozone-related health impacts and monetized benefits. There is no analogous approach for estimating a BPT for

[20] The Transport Rule includes both SO_2 and NOx emissions reductions. In general SO_2 is a precursor to particulate sulfate and NOx is a precursor to particulate nitrate. However, there are also several interactions between the $PM_{2.5}$ precursors which cannot be easily quantified. For example, under conditions in which SO_2 levels are reduced by a substantial margin, "nitrate replacement" may occur. This occurs when particulate ammonium sulfate concentrations are reduced, thereby freeing up excess gaseous ammonia. The excess ammonia is then available to react with gaseous nitric acid to form particulate nitrate. The impact of nitrate replacement is also affected by concurrent NOx reductions. NOx reductions can lead to decreases in nitrate, which competes with the process of nitrate replacement. NOx reductions can also lead to reductions in photochemical by-products which can reduce both particulate sulfate and secondary organic carbon PM concentrations. Due to the complex nature of these interactions, EPA performed a sensitivity modeling analysis in which only SO_2 emissions were reduced at levels that approximated those of the selected remedy. We calculated benefits from this air quality modeling run to generate an SO_2-only benefit per ton estimate. The results of the SO_2-only sensitivity run may be found in the EPA Benefits TSD [Docket No. EPA-HQ-OAR-2010-0491]

visibility, and so the benefits of the alternative remedies omit this important monetized benefit.

5.3 Uncertainty Characterization

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty and this analysis is no exception. As outlined both in this and preceding chapters, many inputs were used to derive the estimate of benefits for the proposed remedy, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological health effect estimates, estimates of values (both from WTP and COI 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 its role in the benefits analysis, may have a disproportionately large impact on 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 large impacts on total benefits.

The National Research Council (NRC) (2002, 2008) highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In general, the NRC concluded that EPA's general methodology for calculating the benefits of reducing air pollution is reasonable and informative in spite of inherent uncertainties. Since the publication of these reports, EPA's Office of Air and Radiation (OAR) continues to make progress toward the goal of characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates in two key ways: Monte Carlo analysis and expert-derived concentration-response functions. In this analysis, we use both of these two methods to assess uncertainty quantitatively, as well as provide a qualitative assessment for those aspects that we are unable to address quantitatively.

First, we used Monte Carlo methods for characterizing random sampling error associated with the concentration response functions from epidemiological studies and random effects modeling to characterize both sampling error and variability across the economic valuation functions. Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables, such as incidence of premature mortality. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and dollar benefits. The reported standard errors in the epidemiological studies determined the distributions for individual effect estimates.

Second, because characterization of random statistical error omits important sources of uncertainty (e.g., in the functional form of the model—e.g., whether or not a threshold may exist), we also incorporate the results of an expert elicitation on the relationship between premature mortality and ambient $PM_{2.5}$ concentration (Roman et al., 2008). Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. However, there are significant unquantified uncertainties present in upstream inputs including emission and air quality. Both approaches have different strengths and weaknesses, which are fully described in Chapter 5 of the PM NAAQS RIA (U.S. EPA, 2006).

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85% to 95% of total monetized benefits. Therefore, it is particularly important to attempt to characterize the uncertainties associated with reductions in premature mortality. The health impact functions used to estimate avoided premature deaths associated with reductions in ozone have associated standard errors that represent the statistical errors around the effect estimates in the underlying epidemiological studies. In our results, we report credible intervals based on these standard errors, reflecting the uncertainty in the estimated change in incidence of avoided premature deaths. We also provide multiple estimates, to reflect model uncertainty between alternative study designs.

For premature mortality associated with exposure to PM, we follow the same approach used in the RIA for 2006 PM NAAQS (U.S. EPA, 2006), presenting two empirical estimates of premature deaths avoided, and a set of twelve estimates based on results of the expert elicitation study. Even these multiple characterizations, including confidence intervals, omit the contribution to overall uncertainty of uncertainty in air quality changes, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. Furthermore, the approach presented here does not yet include methods for addressing correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

In 2006 the EPA requested an NAS study to evaluate the extent to which the epidemiological literature to that point improved the understanding of ozone-related mortality. The NAS found that short-term ozone exposure was likely to contribute to ozone-related mortality (NRC, 2008) and issued a series of recommendations to EPA, including that the Agency should:

1. Present multiple short-term ozone mortality estimates, including those based on multi-city analyses such as the National Morbidity, Mortality and Air Pollution Study (NMMAPS) as well as meta-analytic studies.
2. Report additional risk metrics, including the percentage of baseline mortality attributable to short-term exposure.
3. Remove reference to a no-causal relationship between ozone exposure and premature mortality.

The quantification and presentation of ozone-related premature mortality in this chapter is responsive to these NRC recommendations and generally consistent with EPA's recent ozone reconsideration analysis (U.S. EPA, 2010a).

Some key sources of uncertainty in each stage of both the PM and ozone health impact assessment are the following:

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

In Table 5-3 we summarize some of the key uncertainties in the benefits analysis.

Table 5-3. Primary Sources of Uncertainty in the Benefits Analysis

1. Uncertainties Associated with Impact Functions
- The value of the ozone or PM effect estimate in each impact function. - Application of a single impact function to pollutant changes and populations in all locations. - Similarity of future-year impact functions to current impact functions. - Correct functional form of each impact function. - Extrapolation of effect estimates beyond the range of ozone or PM concentrations observed in the source epidemiological study. - Application of impact functions only to those subpopulations matching the original study population.
2. Uncertainties Associated with CAMx-Modeled Ozone and PM Concentrations
- Responsiveness of the models to changes in precursor emissions from the control policy. - Projections of future levels of precursor emissions, especially ammonia and crustal materials. - Lack of ozone and $PM_{2.5}$ monitors in all rural areas requires extrapolation of observed ozone data from urban to rural areas.
3. Uncertainties Associated with PM Mortality Risk
- Limited scientific literature supporting a direct biological mechanism for observed epidemiological evidence. - Direct causal agents within the complex mixture of PM have not been identified. - The extent to which adverse health effects are associated with low-level exposures that occur many times in the year versus peak exposures. - The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. - Reliability of the $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated with Possible Lagged Effects
- The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels that would occur in a single year is uncertain as well as the portion that might occur in subsequent years.
5. Uncertainties Associated with Baseline Incidence Rates
- Some baseline incidence rates are not location specific (e.g., those taken from studies) and therefore may not accurately represent the actual location-specific rates. - Current baseline incidence rates may not approximate well baseline incidence rates in 2014. - Projected population and demographics may not represent well 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 because of differences in income or other factors.
7. Uncertainties Associated with Aggregation of Monetized Benefits
- Health and welfare benefits estimates are limited to the available impact functions. Thus, unquantified or unmonetized benefits are not included.

5%, 3%, and 2.5%) rather than 3% and 7%.[50] These estimates are provided in Table 5-16.

Table 5-15. Social Cost of Carbon (SCC) Estimates (per tonne of CO_2) for 2014 (in 2007$)[a]

Discount Rate and Statistic		*SCC estimate*
5%	Average	$5.5
3%	Average	$23.4
2.5%	Average	$37.7
3%	95%ile	$71.2

[a] The SCC values are dollar-year and emissions-year specific. SCC values represent only a partial accounting of climate impacts.

Table 5-16. Monetized SCC-Derived Benefits of CO_2 Emissions Reductions in 2014 (in millions of 2007$)[a]

Discount Rate and Statistic		*SCC-derived benefits*
Tons of CO_2 reduced (millions)		25
5%	Average	$140
3%	Average	$590
2.5%	Average	$950
3%	95%ile	$1,800

[a] The SCC values are dollar-year and emissions-year specific. SCC values represent only a partial accounting of climate impacts.

5.7 Benefits Results

Applying the impact and valuation functions described previously in this chapter to the estimated changes in ozone and PM yields estimates of the changes in physical damages (e.g., premature mortalities, cases, admissions, and change in light extinction) and the associated monetary values for those changes. Estimates of physical health impacts among those states in either the ozone or $PM_{2.5}$ trading region, or outside the trading region, are presented in Table 5-17. Monetized values for both health and welfare endpoints within the trading region are presented in Table 5-18, along with total aggregate monetized benefits. All of the monetary benefits are in constant-year 2007 dollars. The $PM_{2.5}$-related benefits of the more and less stringent scenarios were within about 15% of the selected remedy. The results

[50] It is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

of that analysis may be found in the cost-benefit comparison chapter (Chapter 10 of this RIA).

Table 5-17: Estimated Reduction in Incidence of Adverse Health Effects of the Selected remedy (95% confidence intervals)[A]

Health Effect		*Within transport region*	*Beyond transport region*	*Total*
PM-Related endpoints				
Premature Mortality				
	Pope et al. (2002) (age >30)	13,000 (5,200—21,000)	33 (5—60)	13,000 (5,200—21,000)
	Laden et al. (2006) (age >25)	34,000 (18,000—49,000)	84 (31—140)	34,000 (18,000—49,000)
	Infant (< 1 year)	59 (-47—160)	0.15 (-0.2—0.5)	59 (-47—160)
Chronic Bronchitis		8,700 (1,600—16,000)	23 (-5—50)	8,700 (1,600—16,000)
Non-fatal heart attacks (age > 18)		15,000 (5,600—24,000)	40 (7—72)	15,000 (5,600—24,000)
Hospital admissions—respiratory (all ages)		2,700 (1,300—4,000)	5 (2—9)	2,700 (1,300—4,000)
Hospital admissions—cardiovascular (age > 18)		5,700 (4,200—6,600)	15 (10—19)	5,800 (4,200—6,600)
Emergency room visits for asthma (age < 18)		9,800 (5,800—14,000)	21 (7—36)	9,800 (5,800—14,000)
Acute bronchitis (age 8-12)		19,000 (-630—37,000)	50 (-29—130)	19,000 (-660—37,000)
Lower respiratory symptoms (age 7-14)		240,000 (120,000—360,000)	630 (130—1,100)	240,000 (120,000—360,000)
Upper respiratory symptoms (asthmatics age 9-18)		180,000 (57,000—310,000)	480 (-25—980)	180,000 (57,000—310,000)
Asthma exacerbation (asthmatics 6-18)		400,000 (45,000—1,100,000)	1,100 (-250—2,900)	400,000 (45,000—1,100,000)
Lost work days (ages 18-65)		1,700,000 (1,500,000—1,900,000)	4,300 (3,500—5,200)	1,700,000 (1,500,000—1,900,000)
Minor restricted-activity days (ages 18-65)		10,000,000 (8,400,000—11,000,000)	26,000 (20,000—32,000)	10,000,000 (8,400,000—12,000,000)
Ozone-related endpoints				
Premature mortality				
	Bell et al. (2004) (all ages)	27 (11—42)	0.1 (0.01—0.3)	27 (11—42)

	Schwartz et al. (2005) (all ages)	41 (17—64)	0.2 (0.1—0.4)	41 (17—65)
	Huang et al. (2005) (all ages)	37 (17—57)	0.2 (0.1—0.4)	37 (17—57)
Meta-analyses	Ito et al. (2005) (all ages)	120 (78—160)	0.6 (0.3—0.9)	120 (79—160)
Meta-analyses	Bell et al. (2005) (all ages)	87 (48—130)	0.5 (0.2—0.8)	87 (48—130)
Meta-analyses	Levy et al. (2005) (all ages)	120 (89—150)	0.7 (0.4—0.9)	120 (90—160)
Hospital admissions—respiratory causes (ages > 65)		160 (21—280)	1.2 (0.1—2.3)	160 (21—290)
Hospital admissions—respiratory causes (ages <2)		83 (43—120)	0.5 (0.2—0.8)	84 (43—120)
Emergency room visits for asthma (all ages)		86 (-2—260)	0.4 (-0.2—1.4)	86 (-2—260)
Minor restricted-activity days (ages 18-65)		160,000 (80,000—240,000)	910 (240—1,600)	160,000 (80,000—240,000)
School absence days		51,000 (22,000—73,000)	290 (59—490)	51,000 (22,000—74,000)

[A] Estimates rounded to two significant figures; column values will not sum to total value.
[B] The negative estimates for certain endpoints are the result of the weak statistical power of the study used to calculate these health impacts and do not suggest that increases in air pollution exposure result in decreased health impacts.

Table 5-18: Estimated Economic Value of Health and Welfare Benefits (95% confidence intervals, billions of 2007$)[A]

Health Effect	*Pollutant*	*Within transport region*	*Beyond transport region*[B]	*Total*
Premature Mortality (Pope et al. 2002 PM mortality and Bell et al. 2004 ozone mortality estimates)				
3% discount rate	$PM_{2.5}$ & O_3	$100 ($8.3—$320)	$0.3 ($0.01—$0.9)	$100 ($8.3—$320)
7% discount rate	$PM_{2.5}$ & O_3	$94 ($7.5—$280)	$0.2 ($0.01—$0.8)	$94 ($7.5—$290)
Premature Mortality (Laden et al. 2006 PM mortality and Levy et al. 2005 ozone mortality estimates)				
3% discount rate	$PM_{2.5}$ & O_3	$270 ($23—$770)	$0.7 ($0.05—$2)	$270 ($23—$770)
7% discount rate	$PM_{2.5}$ & O_3	$240 ($21—$700)	$0.6 ($0.05—$1.8)	$240 ($21—$700)
Chronic Bronchitis	$PM_{2.5}$	$4.2 ($0.2—$19)	$0.01 ($-0.003--$0.06)	$4.2 ($0.2—$19)
Non-fatal heart attacks				
3% discount rate	$PM_{2.5}$	$1.7 ($0.3—$4.2)	$0.004 ($0.003—$0.01)	$1.7 ($0.3—$4.2)
7% discount rate	$PM_{2.5}$	$1.3 ($0.3—$3.1)	$0.004 ($0.002—$0.001)	$1.3 ($0.3—$3.1)
Hospital admissions—respiratory	$PM_{2.5}$ & O_3	$0.04 ($0.02—$0.06)	---	$0.04 ($0.02—$0.06)
Hospital admissions—cardiovascular	$PM_{2.5}$	$0.09 ($0.01—$0.2)	---	$0.09 ($0.01—$0.2)
Emergency room visits for asthma	$PM_{2.5}$ & O_3	$0.003 ($0.002—$0.006)	---	$0.003 ($0.002—$0.006)
Acute bronchitis	$PM_{2.5}$	$0.008 (<$-0.01—$0.02)[c]	---	$0.008 (<$-0.01—$0.02)[c]
Lower respiratory symptoms	$PM_{2.5}$	$0.004 ($0.002—$0.009)	---	$0.004 ($0.002—$0.009)
Upper respiratory symptoms	$PM_{2.5}$	$0.005 (<$0.01—$0.014)	---	$0.005 (<$0.01—$0.014)
Asthma exacerbation	$PM_{2.5}$	$0.02 ($0.002—$0.08)	---	$0.02 ($0.002—$0.08)
Lost work days	$PM_{2.5}$	$0.2 ($0.17—$0.24)	---	$0.2 ($0.17—$0.24)
School loss days	O_3	$0.01 ($0.004—$0.013)	---	$0.01 ($0.004—$0.013)
Minor restricted-activity days	$PM_{2.5}$ & O_3	$0.7 ($0.3—$1)	---	$0.7 ($0.3—$1)

Recreational visibility, Class I areas	$PM_{2.5}$			$4.1
Social cost of carbon (3% discount rate, 2014 value)	CO_2			$0.6
Monetized total Benefits (Pope et al. 2002 $PM_{2.5}$ mortality and Bell et al. 2004 ozone mortality estimates)				
3% discount rate	$PM_{2.5}$, O_3	**$110 ($8.8—$340)**	**$0.28 ($0.01—$0.9)**	**$120 ($14—$350)**
7% discount rate	$PM_{2.5}$, O_3	**$100 ($8—$310)**	**$0.25 ($0.01—$0.85)**	**$110 ($13—$320)**
Monetized total Benefits (Laden et al. 2006 $PM_{2.5}$ mortality and Levy et al. 2005 ozone mortality estimates)				
3% discount rate	$PM_{2.5}$, O_3	**$270 ($24—$800)**	**$0.7 ($0.05—$2.1)**	**$280 ($29—$810)**
7% discount rate	$PM_{2.5}$, O_3	**$250 ($22—$720)**	**$0.6 ($0.04—$1.9)**	**$250 ($26—$730)**

[A] Estimates rounded to two significant figures.
[B] Monetary value of endpoints marked with dashes are < $100,000. States included in transport region may be found in chapter 2.
[C] The negative estimates for certain endpoints are the result of the weak statistical power of the study used to calculate these health impacts and do not suggest that increases in air pollution exposure result in decreased health impacts.

Not all known PM- and ozone-related health and welfare effects could be quantified or monetized. The monetized value of these unquantified effects is represented by adding an unknown “B” to the aggregate total. The estimate of total monetized health benefits is thus equal to the subset of monetized PM- and ozone-related health and welfare benefits plus B, the sum of the nonmonetized health and welfare benefits; this B represents both uncertainty and a bias in this analysis, as it reflects those benefits categories that we are unable quantify in this analysis.

Total monetized benefits are dominated by benefits of mortality risk reductions. The primary analysis projects that the preferred remedy will result in between 13,000 and 34,000 $PM_{2.5}$ and ozone-related avoided premature deaths annually in 2014. Our estimate of total monetized benefits in 2014 for the selected remedy is between $120 billion and $280 billion using a 3 percent discount rate and between $110 billion and $250 using a 7 percent discount rate. Health benefits account for between 97 and 99 percent of total benefits depending on the $PM_{2.5}$ and ozone mortality estimates used, in part because we are unable to quantify most of the non-health benefits. The monetized benefit associated with reductions in the risk of premature mortality, which accounts for between $100 and $270 billion in 2014, depending again on the PM and ozone mortality risk estimates used, is between 93 and 97 percent of total monetized health benefits. The next largest benefit is for reductions in chronic illness (CB and nonfatal heart attacks), although this value is more than an order of magnitude lower than for premature mortality. Hospital admissions for respiratory and cardiovascular causes, visibility, MRADs, work loss days, school absence days, and worker productivity account for the majority of the remaining benefits. The remaining categories each account for a small percentage of total benefit; however, they represent a large number of avoided incidences affecting many individuals. A comparison of the incidence table to the monetary benefits table reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there are almost 100 times more work loss days than premature mortalities, yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of WTP. As such, the true value of these effects may be higher than that reported in Table 5-18.

Figures 5-15 and 5-16 illustrates the geographic distribution of avoided $PM_{2.5}$ and ozone-related mortalities estimated to result from the selected remedy. Figure 5-17 plots the cumulative distribution of the percentage of deaths due to PM2.5 and ozone in 2014, prior to and after the implementation of the Transport Rule remedy. As illustrated in this figure, once implemented the Transport Rule is estimated to reduce by a substantial fraction the percentage of total deaths due to $PM_{2.5}$ and ozone. While not quantified in this RIA, we expect the Transport Rule to produce important public health benefits for populations living in Canada. Approximately 90% of the Canadian population lives within 100 miles of the U.S. border, suggesting that some of the air quality improvements projected in areas near the U.S.-Canada border would be enjoyed by Canadian populations as well. A recent analysis (Chestnut and Mills, 2005) of the U.S. Acid Rain Program estimates annual benefits of the program in 2010 to both Canada and the United States at $122 billion and costs for that year at $3 billion (2000$)—a 40-to-1 benefit/cost ratio. These quantified benefits in the United States and Canada are the result of improved air quality prolonging lives, reducing heart attacks and other cardiovascular and respiratory problems, and improving visibility. The complete report is available in volume 77, issue 3, of the *Journal of Environmental*

Management.

These figures show that while there are very large health benefits throughout most of the East, there could be several areas where a very small disbenefit could result if further governmental actions do not occur to address them in the future. There are several upcoming planned federal actions that could lead to further large reductions throughout the US of ambient levels of fine particles and ozone. Additionally, state actions to address regional haze in the near future and the existing NAAQS for fine particles and ozone could address these situations. There are also other state actions, such as the recent Colorado Clean Air – Clean Jobs Act of April 2010 that is likely to convert much of the Front Range coal-fired generation in Colorado to natural gas in the near future.

Figure 5-15: Estimated reduction in excess $PM_{2.5}$-related premature mortalities estimated to occur in each county in 2014 as a result of the selected remedy.

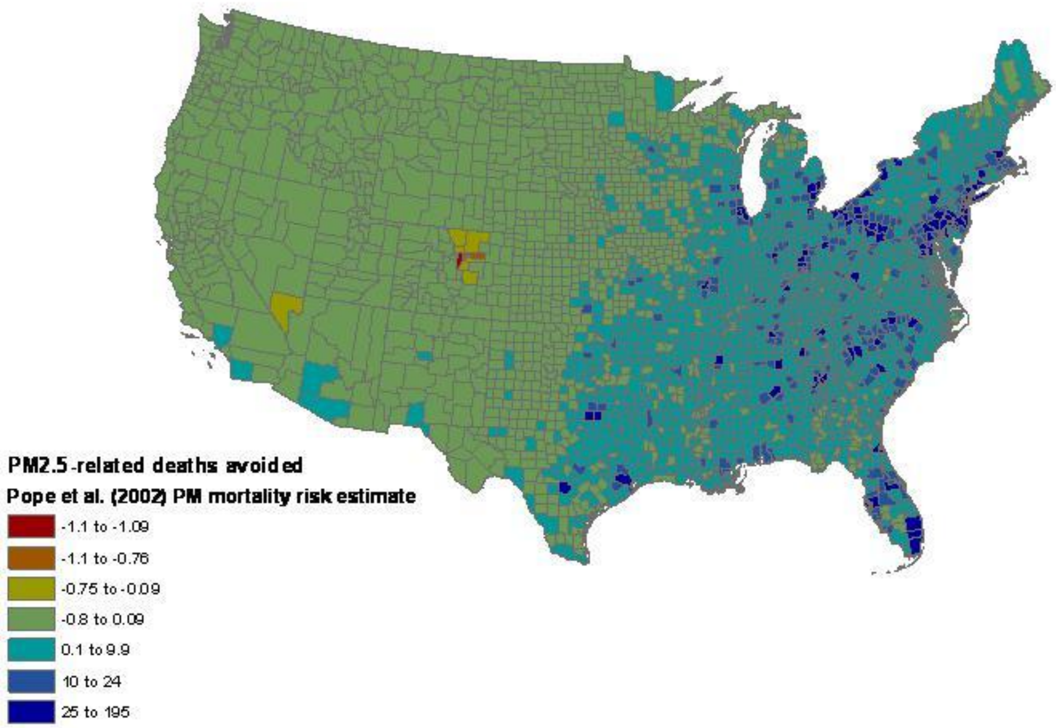


Figure 5-16: Estimated reduction in excess ozone-related premature mortalities estimated to occur in each county in 2014 as a result of the selected remedy

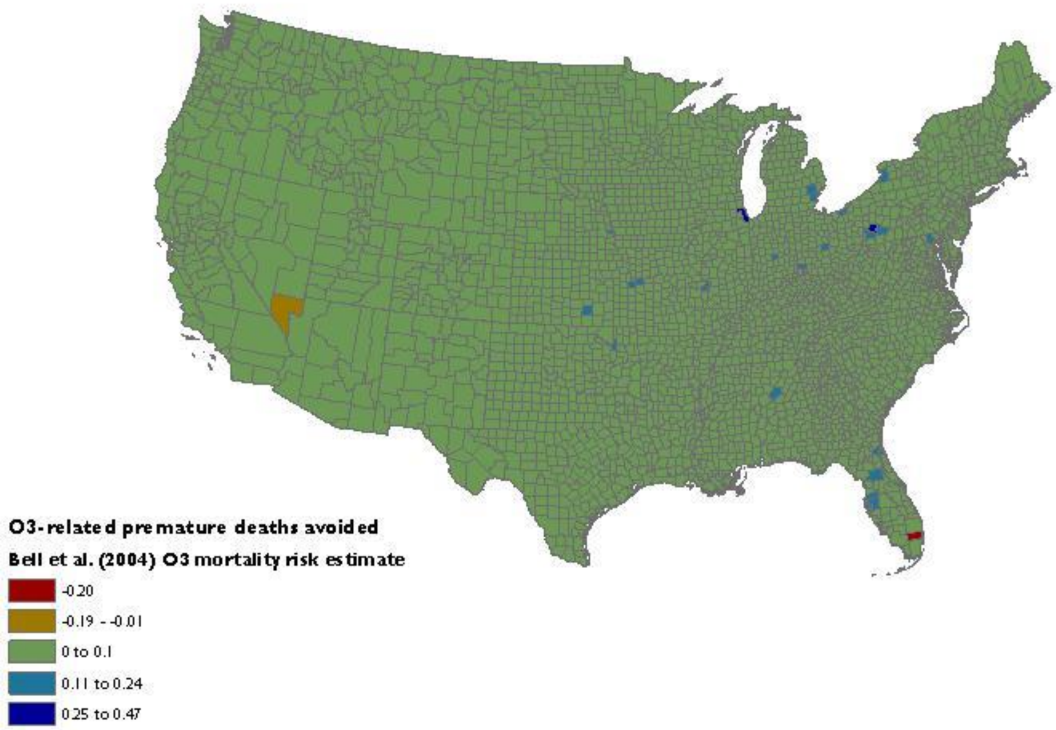
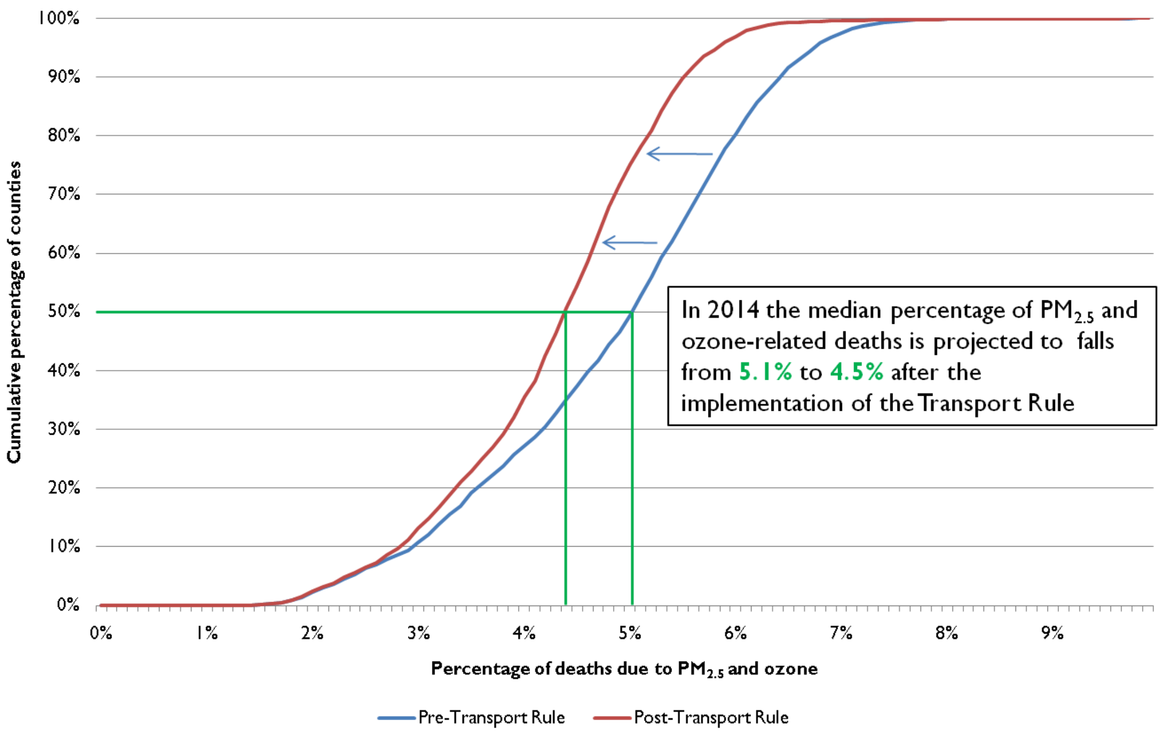


Figure 5-17: Cumulative percentage of the reduction in all-cause mortality attributable to reductions in $PM_{2.5}$ and Ozone resulting from the selected remedy by county in 2014[A]



[A]Bell et al. 2005 ozone mortality estimate and Pope et al. 2002 $PM_{2.5}$ mortality estimates.

Figure 5-18 summarizes an array of $PM_{2.5}$-related monetized benefits estimates based on alternative epidemiology and expert-derived PM-mortality estimate as well as the sum of ozone-related benefits using the Bell et al. (2004) mortality estimate.

Based on our review of the current body of scientific literature, EPA estimated PM-related mortality without applying an assumed concentration threshold. EPA's Integrated Science Assessment for Particulate Matter (U.S. EPA, 2009b), which was recently reviewed by EPA's Clean Air Scientific Advisory Committee (U.S. EPA-SAB, 2009a; U.S. EPA-SAB, 2009b), concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function. Consistent with this finding, we have conformed the threshold sensitivity analysis to the current state of the PM science improved upon our previous approach for estimating the sensitivity of the benefits estimates to the presence of an assumed threshold by incorporating a new "Lowest Measured Level" (LML) assessment.

This approach summarizes the distribution of avoided PM mortality impacts according to the baseline (i.e. pre-Transport Rule) $PM_{2.5}$ levels experienced by the population receiving the $PM_{2.5}$ mortality benefit (Figure 5-19). We identify on this figure the lowest air quality levels measured in each of the two primary epidemiological studies EPA uses to quantify PM-related mortality. This information allows readers to determine the portion of PM-related mortality benefits occurring above or below the LML of each study; in general, our confidence in the estimated PM mortality decreases as we consider air quality levels further below the LML in the two epidemiological studies. While the LML analysis provides some insight into the level of uncertainty in the estimated PM mortality benefits, EPA does not view the LML as a threshold and continues to quantify PM-related mortality impacts using a full range of modeled air quality concentrations.

The very large proportion of the avoided PM-related impacts we estimate in this analysis occur among populations exposed at or above the LML of each study (Figures 5-19) increasing our confidence in the PM mortality analysis. Approximately 69% of the avoided impacts occur at or above an annual mean $PM_{2.5}$ level of 10 $\mu g/m^3$ (the LML of the Laden et al. 2006 study); about 96% occur at or above an annual mean $PM_{2.5}$ level of 7.5 $\mu g/m^3$ (the

LML of the Pope et al. 2002 study). As we model mortality impacts among populations exposed to levels of $PM_{2.5}$ that are successively lower than the LML of each study our confidence in the results diminishes. However, the analysis above confirms that the great majority of the impacts occur at or above each study's LML.

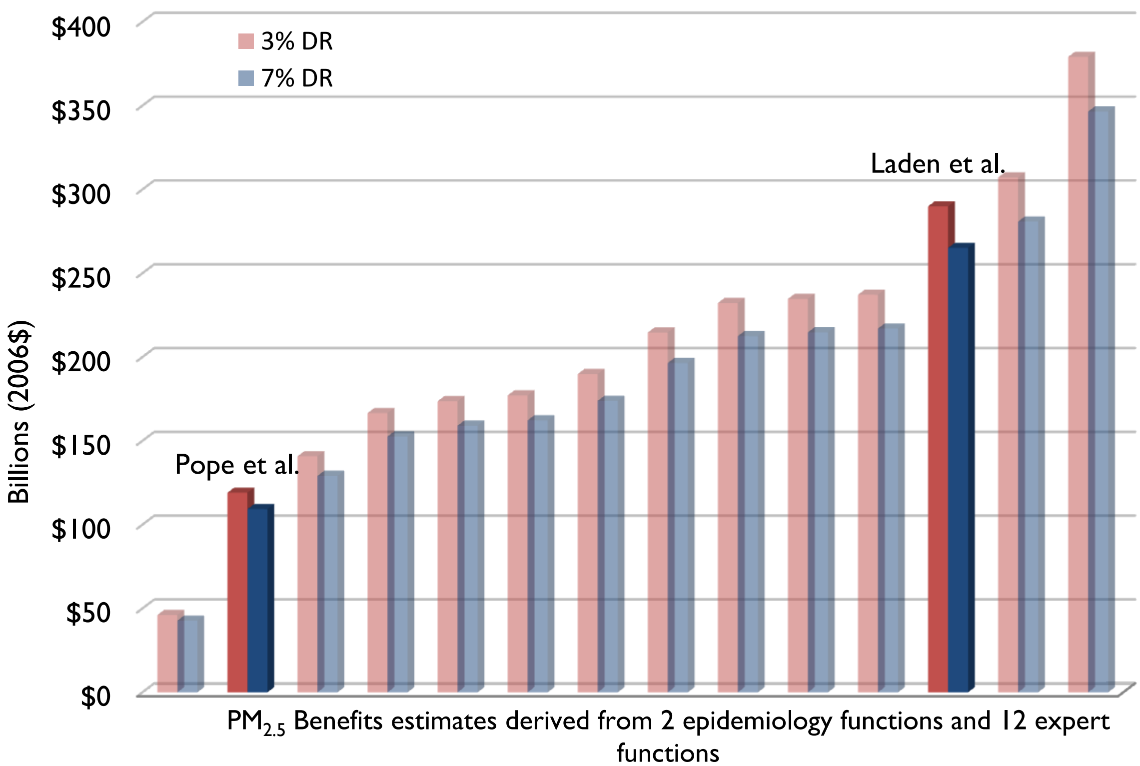
As an example, when considering mortality impacts among populations living in areas with an annual mean PM level of 8 µg/m3, we would place greater confidence in estimates drawn from the Pope et al. 2002 study, as this air quality level is above the LML of this study. Conversely, we would place equal confidence when estimating mortality impacts among populations living in locations where the annual mean PM levels are above 10 µg/m3 because this value is at or above the LML of each study.

Finally, Figure 5-20 illustrates the percentage of population exposed to different levels of annual mean PM2.5 levels in the baseline and after the implementation of the Transport Rule in 2014. The Transport Rule reduces overall PM2.5 levels substantially, particularly among highly exposed populations located within the states covered by the rule. Locations of the U.S. where annual mean PM levels are below the lowest measured level of the Pope study--western states in particular--are generally unaffected by the rule. However, for populations in the far western portion of the Transport Rule region, where annual mean $PM_{2.5}$ concentrations are below 7.5 µg /m3, there are benefits of the rule, although the relative magnitude of those benefits compared to benefits in the majority of the areas covered by the Transport Rule is small. In these areas there is lower confidence in the magnitude of the benefits associated with reductions in long-term $PM_{2.5}$. However, in these same areas, there may be additional benefits associated with short term elevated levels of PM, and there is relatively greater confidence in those benefits. In addition, we note that prior to the implementation of the Transport Rule, 85% of the population live in areas where $PM_{2.5}$ levels are projected to be above the lowest measured levels of the Pope study. Taken together, this information increases our confidence in the estimated mortality reductions for this rule.

While the LML of each study is important to consider when characterizing and interpreting the overall level PM-related benefits, as discussed earlier in this chapter, EPA believes that both cohort-based mortality estimates are suitable for use in air pollution health impact analyses. When estimating PM mortality impacts using risk coefficients drawn from the Laden et al. analysis of the Harvard Six Cities and the Pope et al. analysis of the

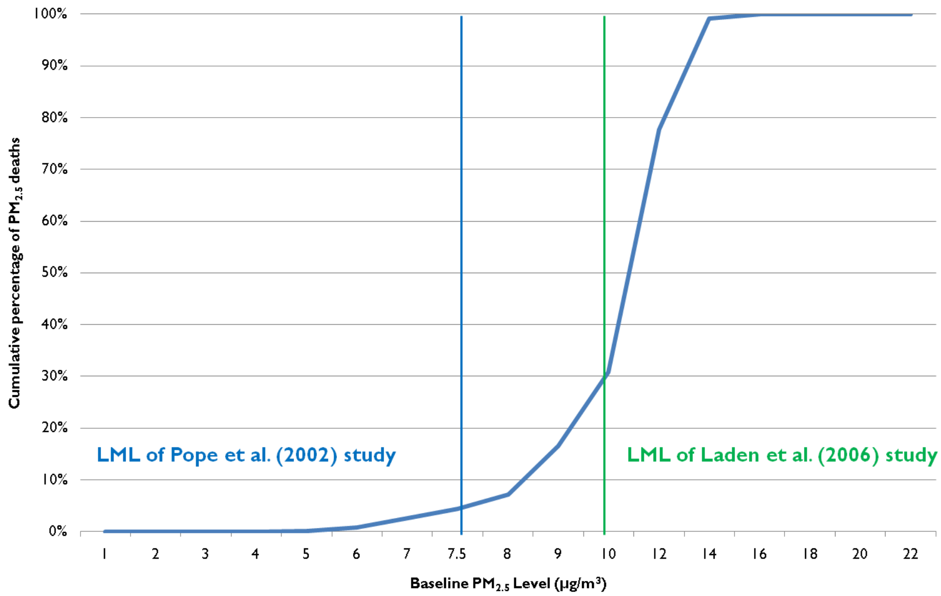
American Cancer Society cohorts there are innumerable other attributes that may affect the size of the reported risk estimates—including differences in population demographics, the size of the cohort, activity patterns and particle composition among others. The LML assessment presented here provides a limited representation of one key difference between the two studies.

Figure 5-18: Estimated $PM_{2.5}$- related premature mortalities avoided according to epidemiology or expert-derived PM mortality risk estimate[A]



[A] Column total equals sum of $PM_{2.5}$-related mortality and morbidity benefits and ozone-related morbidity and mortality benefits using the Bell et al. (2004) mortality estimate.

Figure 5-19: Distribution of $PM_{2.5}$-related mortality impacts by baseline $PM_{2.5}$ levels, $PM_{2.5}$ epidemiology study and lowest measured level (LML) of each study

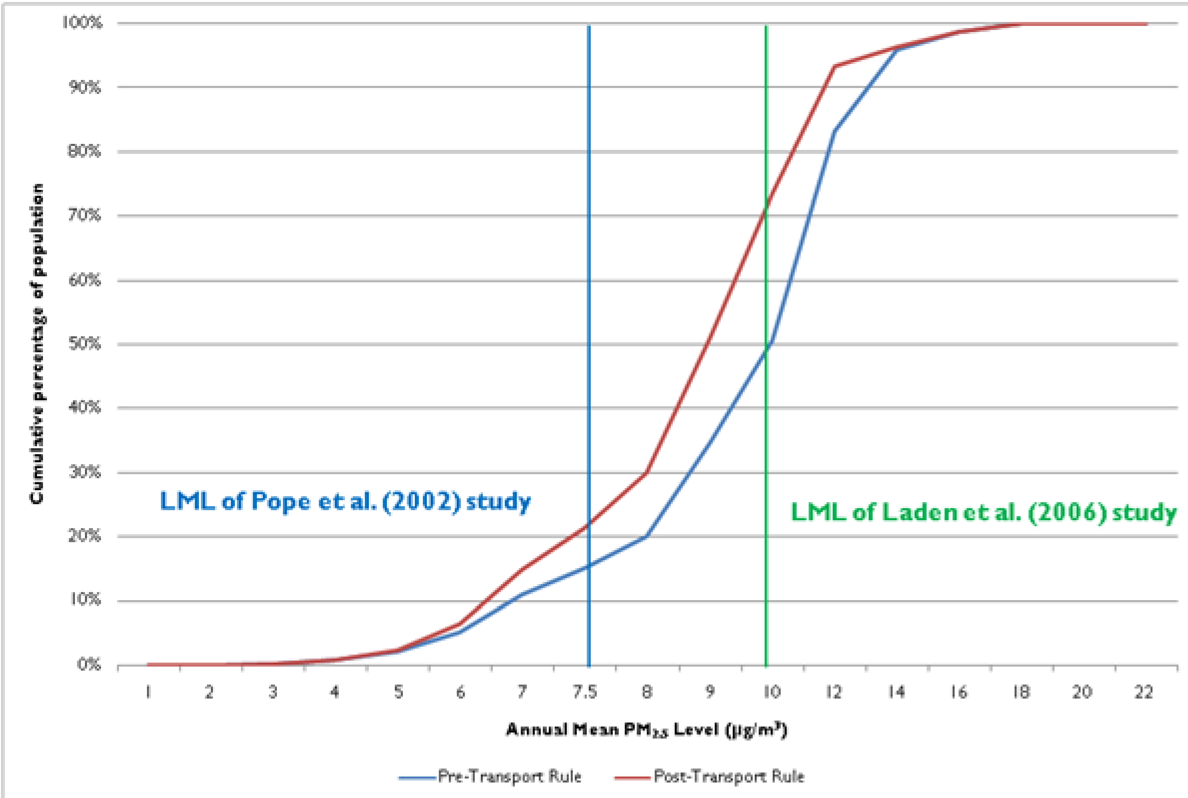


Of the deaths avoided:

96% occur among populations exposed to PM levels at or above the LML of the **Pope et al. (2002) study**

69% occur among populations exposed to PM levels at or above the LML of the **Laden et al. (2006) study**

Figure 5-20: Cumulative percentage of adult population at annual mean $PM_{2.5}$ levels (pre- and post-2014 Transport Rule)



5.8 Discussion

This analysis demonstrates the significant health and welfare benefits of the Transport Rule. We estimate that by 2014 the rule will have reduced the number of $PM_{2.5}$ and ozone-related premature mortalities by between 13,000 and 34,000, produce substantial non-mortality benefits and significantly improve visibility in Class 1 areas. This rule promises to yield significant welfare impacts as well, though the quantification of those endpoints in this RIA is incomplete. These significant health and welfare benefits suggest the important role that pollution from the EGU sector plays in the public health impacts of air pollution.

Inherent in any complex RIA such as this one are multiple sources of uncertainty. Some of these we characterized through our quantification of statistical error in the concentration response relationships and our use of the expert elicitation-derived PM mortality functions. Others, including the projection of atmospheric conditions and source-level emissions, the projection of baseline morbidity rates, incomes and technological development are unquantified. When evaluated within the context of these uncertainties, the health impact and monetized benefits estimates in this RIA can provide useful information regarding the public health impacts attributable to EGUs.

5.9 References

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