Regulatory Impact Analysis
for the
Clean Power Plan Final Rule

The original version of this document was replaced on October 23, 2015, to incorporate the technical corrections listed on page ii.

ERRATA SHEET

In conjunction with the memorandum titled *Correction of Inadvertent Errors in the Final Rule "Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units" and Associated Supporting Documents*, the Clean Power Plan Final Rule Regulatory Impact Analysis (RIA) was updated to incorporate the technical corrections listed in this errata sheet. None of these technical corrections affect the analysis or results.

Location(s)	*Error*	*Correction*
Table 2-2 title, Table 2-2 column header	"2013"	"2012"
Table 2-2 column header	"Change Between '02 and '13"	"Change Between '02 and '12"
Page 3-2	"IPM (v5.154)"	"IPM (v5.15)"
Page 3-7	"Existing NGCC units with nameplate capacity greater than 25 MW"	"Existing NGCC units"
Pages 1-5, 1-8, 3-2, 3-3, 3-5, 3-22, 3-36, 4A-7, 6A-2	"http://www.epa.gov/powersectormodeling/"	"http://www.epa.gov/airmarkets/powersectormodeling.html"
Page 3-44	" http:// http://www.epa.gov/powersectormodeling/"	"http://www.epa.gov/airmarkets/powersectormodeling.html"
Page 1-8	"http://www.epa.gov/powersectormodeling/psmodel514.html"	"http://www.epa.gov/airmarkets/powersectormodeling.html"
Page 4A-7	"http://www.epa.gov/powersectormodeling/docs/v513/FlatFile_Methodology.pdf"	"http://www.epa.gov/airmarkets/powersectormodeling.html"

the changes in upstream methane emissions are small relative to the changes in direct emissions from power plants.

4.3 Estimated Human Health Co-Benefits

In addition to reducing emissions of CO_2, implementing these final emission guidelines is expected to reduce emissions of SO_2 and NO_X, which are precursors to formation of ambient $PM_{2.5}$, as well as directly emitted fine particles.[101] Therefore, reducing these emissions would also reduce human exposure to ambient $PM_{2.5}$ and the incidence of $PM_{2.5}$-related health effects. In addition, in the presence of sunlight, NO_X and VOCs can undergo a chemical reaction in the atmosphere to form ozone. Depending on localized concentrations of volatile organic compounds (VOCs), reducing NO_X emissions would also reduce human exposure to ozone and the incidence of ozone-related health effects. Although we do not have sufficient data to quantify these impacts in this analysis, reducing emissions of SO_2 and NOx would also reduce ambient exposure to SO_2 and NO_2 and their associated health effects, respectively. In this section, we provide an overview of the monetized $PM_{2.5}$ and ozone-related co-benefits estimated for the final emission guidelines. A full description of the underlying data, studies, and assumptions is provided in the PM NAAQS RIA (U.S. EPA, 2012a) and Ozone NAAQS RIA (U.S. EPA, 2008b, 2010d). The estimated co-benefits associated with these emission reductions are beyond those achieved by previous EPA rulemakings, including MATS.

There are several important considerations in assessing the air quality-related health co-benefits for a climate-focused rulemaking. First, these estimated health co-benefits do not account for any climate-related air quality changes (e.g., increased ambient ozone associated with higher temperatures) but rather changes in precursor emissions affected by this rulemaking. Excluding climate-related air quality changes may underestimate ozone-related health co-benefits. It is unclear how $PM_{2.5}$-related health co-benefits would be impacted by excluding

[101] In the RIA for the proposed rule, we estimated the health co-benefits associated with emission reductions of two categories of directly emitted particles: elemental carbon plus organic carbon (EC+OC) and crustal. Crustal emissions are composed of compounds associated with minerals and metals from the earth’s surface, including carbonates, silicates, iron, phosphates, copper, and zinc. Often, crustal material represents particles not classified as one of the other species (e.g., organic carbon, elemental carbon, nitrate, sulfate, chloride, etc.). For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

climate-related air quality changes since the science is unclear as to how climate change may affect $PM_{2.5}$ exposure. Second, the estimated health co-benefits also do not consider temperature modification of $PM_{2.5}$ and ozone risks (Roberts 2004; Ren 2006a, 2006b, 2008a, 2008b). Third, the estimated climate benefits reported in this RIA reflect global benefits, while the estimated health co-benefits are calculated for the contiguous U.S. only. Excluding temperature modification of air pollution risks and international air quality-related health benefits likely leads to underestimation of quantified health co-benefits (Anenberg et al, 2009, Jhun et al, 2014). Fourth, as noted earlier, we do not estimate the climate benefits associated with reductions in PM and O_3 precursors.

Implementing the final emission guidelines may lead to reductions in ambient $PM_{2.5}$ concentrations below the National Ambient Air Quality Standards (NAAQS) for PM and ozone in some areas and assist other areas with attaining these NAAQS. Because the NAAQS RIAs (U.S. EPA, 2012a, 2008b, 2010d) also calculated PM and ozone benefits, there are important differences worth noting in the design and analytical objectives of each RIA. The NAAQS RIAs illustrate the potential costs and benefits of attaining a revised air quality standard nationwide based on an array of emission reduction strategies for different sources reflecting the application of known and unknown controls, incremental to implementation of existing regulations and controls needed to attain the current standards. In short, NAAQS RIAs hypothesize, but do not predict, the reduction strategies that States may choose to enact when implementing a revised NAAQS. The setting of a NAAQS does not directly result in costs or benefits, and as such, the EPA's NAAQS RIAs are merely illustrative and the estimated costs and benefits are not intended to be added to the costs and benefits of other regulations that result in specific costs of control and emission reductions. Some of the emissions reductions estimated to result from implementation of the final emission guidelines may achieve some of the air quality improvements that resulted from the hypothesized attainment strategies presented in the illustrative NAAQS RIAs. The emissions reductions from implementing the final emission guidelines will decrease the remaining amount of emissions reductions needed in non-attainment areas and reduce the costs and benefits attributable to meeting the NAAQS.

Similar to NAAQS RIAs, the emission reduction scenarios estimated for the final emission guidelines are also illustrative. In contrast to NAAQS RIAs, all of the emission reductions for the illustrative plan approaches would occur in one well-characterized sector (i.e., the EGU sector). In general, the EPA is more confident in the magnitude and location of the emission reductions for rules which require specific emission reductions in a specific sector, for example, the recent Mercury and Air Toxics Standards. As such, emission reductions achieved under these types of promulgated rules will ultimately be reflected in the baseline of future NAAQS analyses, which would reduce the incremental costs and benefits associated with attaining revised future NAAQS. The EPA does not re-issue illustrative RIAs outside of the rulemaking process that retroactively update the baseline to account for implementation rules promulgated after an RIA was completed. For more information on the relationship between illustrative analyses, such as for the NAAQS and this final emission guidelines, and implementation rules, please see section 1.3 of the PM NAAQS RIA (U.S. EPA, 2012a).

4.3.1 Health Impact Assessment for $PM_{2.5}$ and Ozone

The *Integrated Science Assessment for Particulate Matter* (PM ISA) (U.S. EPA, 2009b) identified the human health effects associated with ambient $PM_{2.5}$ exposure, which include premature mortality and a variety of morbidity effects associated with acute and chronic exposures. Similarly, the *Integrated Science Assessment for Ozone and Related Photochemical Oxidants* (Ozone ISA) (U.S. EPA, 2013b) identified the human health effects associated with ambient ozone exposure, which include premature mortality and a variety of morbidity effects associated with acute and chronic exposures. Table 4-6 identifies the quantified and unquantified co-benefit categories captured in the EPA's health co-benefits estimates for reduced exposure to ambient $PM_{2.5}$ and ozone. Although the table below does not list unquantified health effects such as those associated with exposure to SO_2, NO_2, and mercury nor welfare effects such as acidification and nutrient enrichment, these effects are described in detail in Chapters 5 and 6 of the PM NAAQS RIA (U.S. EPA, 2012a) and summarized later in this chapter. It is important to emphasize that the list of unquantified benefit categories is not exhaustive, nor is quantification of each effect complete.

Table 4-6. Human Health Effects of Ambient $PM_{2.5}$ and Ozone

Category	Specific Effect	Effect Has Been Quantified	Effect Has Been Monetized	More Information
Improved Human Health				
Reduced incidence of premature mortality from exposure to $PM_{2.5}$	Adult premature mortality based on cohort study estimates and expert elicitation estimates (age >25 or age >30)	✓	✓	PM ISA
	Infant mortality (age <1)	✓	✓	PM ISA
Reduced incidence of morbidity from exposure to $PM_{2.5}$	Non-fatal heart attacks (age > 18)	✓	✓	PM ISA
	Hospital admissions—respiratory (all ages)	✓	✓	PM ISA
	Hospital admissions—cardiovascular (age >20)	✓	✓	PM ISA
	Emergency room visits for asthma (all ages)	✓	✓	PM ISA
	Acute bronchitis (age 8-12)	✓	✓	PM ISA
	Lower respiratory symptoms (age 7-14)	✓	✓	PM ISA
	Upper respiratory symptoms (asthmatics age 9-11)	✓	✓	PM ISA
	Asthma exacerbation (asthmatics age 6-18)	✓	✓	PM ISA
	Lost work days (age 18-65)	✓	✓	PM ISA
	Minor restricted-activity days (age 18-65)	✓	✓	PM ISA
	Chronic Bronchitis (age >26)	—	—	PM ISA[1]
	Emergency room visits for cardiovascular effects (all ages)	—	—	PM ISA[1]
	Strokes and cerebrovascular disease (age 50-79)	—	—	PM ISA[1]
	Other cardiovascular effects (e.g., other ages)	—	—	PM ISA[2]
	Other respiratory effects (e.g., pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations)	—	—	PM ISA[2]
	Reproductive and developmental effects (e.g., low birth weight, pre-term births, etc.)	—	—	PM ISA[2,3]
	Cancer, mutagenicity, and genotoxicity effects	—	—	PM ISA[2,3]
Reduced incidence of mortality from exposure to ozone	Premature mortality based on short-term study estimates (all ages)	✓	✓	Ozone ISA
	Premature mortality based on long-term study estimates (age 30–99)	—	—	Ozone ISA[1]
Reduced incidence of morbidity from exposure to ozone	Hospital admissions—respiratory causes (age > 65)	✓	✓	Ozone ISA
	Hospital admissions—respiratory causes (age <2)	✓	✓	Ozone ISA
	Emergency department visits for asthma (all ages)	✓	✓	Ozone ISA
	Minor restricted-activity days (age 18–65)	✓	✓	Ozone ISA
	School absence days (age 5–17)	✓	✓	Ozone ISA
	Decreased outdoor worker productivity (age 18–65)	—	—	Ozone ISA[1]
	Other respiratory effects (e.g., premature aging of lungs)	—	—	Ozone ISA[2]
	Cardiovascular and nervous system effects	—	—	Ozone ISA[2]
	Reproductive and developmental effects	—	—	Ozone ISA[2,3]

[1] We assess these co-benefits qualitatively due to data and resource limitations for this analysis, but we have quantified them in sensitivity analyses for other analyses.

[2] We assess these co-benefits qualitatively because we do not have sufficient confidence in available data or methods.

[3] We assess these co-benefits qualitatively because current evidence is only suggestive of causality or there are other significant concerns over the strength of the association.

We follow a "damage-function" approach in calculating benefits, which estimates changes in individual health endpoints (specific effects that can be associated with changes in air quality) and assigns values to those changes assuming independence of the values for those individual endpoints. Because the EPA rarely has the time or resources to perform new research to measure directly, either health outcomes or their values for regulatory analyses, our estimates are based on the best available methods of benefits transfer, which is the science and art of adapting primary research from similar contexts to estimate benefits for the environmental quality change under analysis. In addition to transferring information from other contexts to the context of this regulation, we also use a "benefit-per-ton" approach to estimate the $PM_{2.5}$ and ozone co-benefits in this RIA. Benefit-per-ton approaches apply an average benefit per ton derived from modeling of benefits of specific air quality scenarios to estimates of emissions reductions for scenarios where no air quality modeling is available. Thus, to develop estimates of benefits for this RIA, we are transferring both the underlying health and economic information from previous studies and information on air quality responses to emissions reductions from previous air quality modeling. This section describes the underlying basis for the health and economic valuation estimates that inform the benefit-per-ton estimates, and the subsequent section provides an overview of the benefit-per-ton estimates,[102] which are described in detail in the appendix to this chapter.

The benefit-per-ton approach we use in this RIA relies on estimates of human health responses to exposure to PM and ozone obtained from the peer-reviewed scientific literature. These estimates are used in conjunction with population data, baseline health information, air quality data and economic valuation information to conduct health impact and economic benefits assessments. These assessments form the key inputs to calculating benefit-per-ton estimates. The next sections provide an overview of the health impact assessment (HIA) methodology and additional details on several key elements.

The HIA quantifies the changes in the incidence of adverse health impacts resulting from changes in human exposure to $PM_{2.5}$ and ozone. We use the environmental Benefits Mapping and

[102] We have updated the benefit-per-ton estimates since the proposal RIA. In this RIA, we apply benefit-per-ton estimates that were derived from air quality modeling of the proposed Clean Power Plan (Option 1 State).

Analysis Program – Community Edition (BenMAP-CE) (version 1.1) to systematize health impact analyses by applying a database of key input parameters, including population projections, health impact functions, and valuation functions (Abt Associates, 2012). For this assessment, the HIA is limited to those health effects that are directly linked to ambient $PM_{2.5}$ and ozone concentrations. There may be other indirect health impacts associated with reducing emissions, such as occupational health exposures. Epidemiological studies generally provide estimates of the relative risks of a particular health effect for a given increment of air pollution (often per 10 $\mu g/m^3$ for $PM_{2.5}$ or ppb for ozone). These relative risks can be used to develop risk coefficients that relate a unit reduction in $PM_{2.5}$ to changes in the incidence of a health effect. We refer the reader to the PM NAAQS RIA (U.S. EPA, 2012a) and Ozone NAAQS RIA (U.S. EPA, 2008b, 2010d) for more information regarding the epidemiology studies and risk coefficients applied in this analysis, and we briefly elaborate on adult premature mortality below. The size of the mortality effect estimates from epidemiological studies, the serious nature of the effect itself, and the high monetary value ascribed to reducing risks of premature death make mortality risk reduction the most significant health endpoint quantified in this analysis.

4.3.1.1 Mortality Concentration-Response Functions for $PM_{2.5}$

Considering a substantial body of published scientific literature and reflecting thousands of epidemiology, toxicology, and clinical studies, the PM ISA documents the association between elevated $PM_{2.5}$ concentrations and adverse health effects, including increased premature mortality (U.S. EPA, 2009b). The PM ISA, which was twice reviewed by the Clean Air Scientific Advisory Committee of the EPA's Science Advisory Board (SAB-CASAC) (U.S. EPA-SAB, 2009b, 2009c), concluded that there is a causal relationship between mortality and both long-term and short-term exposure to $PM_{2.5}$ based on the entire body of scientific evidence. The PM ISA also concluded that the scientific literature supports the use of a no-threshold log-linear model to portray the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function. In addition to adult mortality discussed in more detail below, we use effect coefficients from Woodruff *et al.* (1997) to estimate PM-related infant mortality.

For adult PM-related mortality, we use the effect coefficients from the most recent epidemiology studies examining two large population cohorts: the American Cancer Society cohort (Krewski *et al.*, 2009) and the Harvard Six Cities cohort (Lepeule et al, 2012). The PM ISA (U.S. EPA, 2009b) concluded that the ACS and Six Cities cohorts produce the strongest evidence of the association between long-term PM2.5 exposure and premature mortality with support from a number of additional cohort studies. The SAB's Health Effects Subcommittee (SAB-HES) also supported using these two cohorts for analyses of the benefits of PM reductions (U.S. EPA-SAB, 2010a). As both the ACS and Six Cities cohort studies have inherent strengths and weaknesses, we present PM2.5 co-benefits estimates based on benefits-per-ton derived using relative risk estimates from both these cohorts.

As a characterization of uncertainty regarding the adult $PM_{2.5}$-mortality relationship, the EPA graphically presents the $PM_{2.5}$ co-benefits based on benefits-per-ton estimated using C-R functions derived from EPA's expert elicitation study (Roman *et al.*, 2008; IEc, 2006). The primary goal of the 2006 study was to elicit from a sample of health experts probabilistic distributions describing uncertainty in estimates of the reduction in mortality among the adult U.S. population resulting from reductions in ambient annual average $PM_{2.5}$ concentrations. In that study, twelve experts provided independent opinions regarding the $PM_{2.5}$-mortality concentration-response function. Because the experts relied upon the ACS and Six Cities cohort studies to inform their concentration-response functions, the benefits estimates based on the expert responses generally fall between benefits estimates based on these studies (see Figure 4-1). We do not combine the expert results in order to preserve the breadth and diversity of opinion on the expert panel. This presentation of the expert-derived results is generally consistent with SAB advice (U.S. EPA-SAB, 2008), which recommended that the EPA emphasize that "scientific differences existed only with respect to the magnitude of the effect of $PM_{2.5}$ on mortality, not whether such an effect existed" and that the expert elicitation "supports the conclusion that the benefits of $PM_{2.5}$ control are very likely to be substantial". Although it is possible that newer scientific literature could revise the experts' quantitative responses if elicited again, we believe that these general conclusions are unlikely to change.

4.3.1.2 Mortality Concentration-Response Functions for Ozone

In 2008, the National Academies of Science (NRC, 2008) issued a series of recommendations to the EPA regarding the quantification and valuation of ozone-related short-term mortality. Chief among these was that "…short-term exposure to ambient ozone is likely to contribute to premature deaths" and the committee recommended that "ozone-related mortality be included in future estimates of the health benefits of reducing ozone exposures…" The NAS also recommended that "…the greatest emphasis be placed on the multicity and NMMAPS [*National Morbidity, Mortality, and Air Pollution Study]* studies without exclusion of the meta-analyses" (NRC, 2008). In view of the findings of the National Academies panel, we estimate the co-benefits of avoiding short-term ozone mortality using the Bell *et al.* (2004) NMMAPS analysis, the Schwartz (2005) multi-city study, the Huang *et al.* (2005) multi-city study as well as effect estimates from the three meta-analyses (Bell *et al.* (2005), Levy *et al.* (2005), and Ito *et al.* (2005)). These studies are consistent with the studies used in the Ozone NAAQS RIA (U.S. EPA, 2008b, 2010d).[103] For simplicity, we report the ozone mortality estimates in this RIA as a range reflecting application of dollar-per-ton estimates based on Bell *et al.* (2004) and Levy *et al.* (2005) to represent the lowest and the highest co-benefits estimates based on these six ozone mortality studies. In addition, we graphically present in Figure 4-1 the estimated co-benefits based on dollar-per-ton estimates derived from all six studies mentioned above as a characterization of uncertainty regarding the ozone -mortality relationship.

4.3.2 Economic Valuation for Health Co-benefits

After quantifying the change in adverse health impacts, we estimate the economic value of these avoided impacts. Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects by a small amount for a large population. Therefore, the appropriate economic measure is willingness to pay (WTP) for changes in risk of a health effect. For some health effects, such as hospital admissions, WTP estimates are generally not available, so we use the cost of treating or mitigating the effect. These cost-of-illness (COI) estimates generally (although not necessarily 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. The unit values applied in this

[103] Since the EPA received NAS advice, the Agency published the Ozone ISA (U.S. EPA, 2013b) and the second draft Ozone Health Risk and Exposure Assessment (U.S. EPA, 2014a). Therefore, the ozone mortality studies applied in this analysis, while current at the time of the previous Ozone NAAQS RIAs, do not reflect the most updated literature available. The selection of ozone mortality studies used to estimate benefits in RIAs will be revisited in the forthcoming RIA accompanying the on-going review of the Ozone NAAQS.

analysis are provided in Table 5-9 of the PM NAAQS RIA for each health endpoint (U.S. EPA, 2012a).

Avoided premature deaths account for 98 percent of monetized PM-related co-benefits and over 90 percent of monetized ozone-related co-benefits. The economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. The adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economics and public policy analysis community. Following the advice of the SAB's Environmental Economics Advisory Committee (SAB-EEAC), the EPA currently uses the value of statistical life (VSL) approach in calculating estimates of mortality benefits, because we believe this calculation provides the most reasonable single estimate of an individual's willingness to trade off money for reductions in mortality risk (U.S. EPA-SAB, 2000). The VSL approach is a summary measure for the value of small changes in mortality risk experienced by a large number of people.

The EPA continues work to update its guidance on valuing mortality risk reductions, and the Agency consulted several times with the SAB-EEAC on this issue. Until updated guidance is available, the Agency determined that a single, peer-reviewed estimate applied consistently, best reflects the SAB-EEAC advice it has received. Therefore, the EPA has decided to apply the VSL that was vetted and endorsed by the SAB in the *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2014)[104] while the Agency continues its efforts to update its guidance on this issue. This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$).[105] We then adjust this VSL to account for the currency year and to account for income growth from 1990 to the analysis year. Specifically, the VSLs applied in

[104] In the updated *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2010e), the EPA retained the VSL endorsed by the SAB with the understanding that further updates to the mortality risk valuation guidance would be forthcoming.

[105] In 1990$, this base VSL is $4.8 million.

this analysis in 2011$ after adjusting for income growth are $9.9 million for 2020 and $10.1 million for 2025 and 2030.[106]

The Agency is committed to using scientifically sound, appropriately reviewed evidence in valuing mortality risk reductions and has made significant progress in responding to the SAB-EEAC's specific recommendations. In the process, the Agency has identified a number of important issues to be considered in updating its mortality risk valuation estimates. These are detailed in a white paper, "Valuing Mortality Risk Reductions in Environmental Policy" (U.S. EPA, 2010c), which recently underwent review by the SAB-EEAC. A meeting with the SAB on this paper was held on March 14, 2011 and formal recommendations were transmitted on July 29, 2011 (U.S. EPA-SAB, 2011). The EPA is taking SAB's recommendations under advisement.

In valuing $PM_{2.5}$-related premature mortality, we discount the value of premature mortality occurring in future years using rates of 3 percent and 7 percent (OMB, 2003). We assume that there is a "cessation" lag between changes in PM exposures and the total realization of changes in health effects. Although the structure of the lag is uncertain, the EPA follows the advice of the SAB-HES to assume a segmented lag structure characterized by 30 percent of mortality reductions in the first year, 50 percent over years 2 to 5, and 20 percent over the years 6 to 20 after the reduction in $PM_{2.5}$ (U.S. EPA-SAB, 2004c). Changes in the cessation lag assumptions do not change the total number of estimated deaths but rather the timing of those deaths. Because short-term ozone-related premature mortality occurs within the analysis year, the estimated ozone-related co-benefits are identical for all discount rates.

4.3.3 Benefit-per-ton Estimates for $PM_{2.5}$

We used a "benefit-per-ton" approach to estimate the $PM_{2.5}$ co-benefits in this RIA. The EPA has applied this approach in several previous RIAs (e.g., U.S. EPA, 2011b, 2011c, 2012b, 2014a). These benefit-per-ton estimates provide the total monetized human health co-benefits (the sum of premature mortality and premature morbidity), of reducing one ton of $PM_{2.5}$ (or $PM_{2.5}$ precursor such as NO_X or SO_2) from a specified source. Specifically, in this analysis, we

[106] Income growth projections are only currently available in BenMAP through 2024, so both the 2025 and 2030 estimates use income growth only through 2024 and are therefore likely underestimates.

multiplied the benefit-per-ton estimates by the corresponding emission reductions that were generated from air quality modeling of the proposed Clean Power Plan.

The method used to calculate the regional benefit-per-ton estimates is similar to the average EGU sector estimates used for the proposal (U.S. EPA, 2013a), but relies on air quality modeling of the proposed Clean Power Plan. Similar to the proposal, we generated regional benefit-per-ton estimates by aggregating the impacts in BenMAP to the region (i.e., East, West, and California) rather than aggregating to the nation. The appendix to this chapter provides additional detail regarding these calculations.

As noted below in the characterization of uncertainty, all benefit-per-ton estimates have inherent limitations. Specifically, all benefit-per-ton estimates reflect the geographic distribution of the modeled proposal, which may not match the emission reductions anticipated by the final emission guidelines, and they may not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors for any specific location. The regional benefit-per-ton estimates, although less subject to these types of uncertainties than national estimates, still should be interpreted with caution. Even though we assume that all fine particles have equivalent health effects, the benefit-per-ton estimates vary between precursors depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure.

4.3.4 Benefit-per-ton Estimates for Ozone

Similar to $PM_{2.5}$, we used a “benefit-per-ton” approach in this RIA to estimate the ozone co-benefits, which represent the total monetized human health co-benefits (the sum of premature mortality and premature morbidity) of reducing one ton of NOx (an ozone precursor). Also consistent with the $PM_{2.5}$ estimates, we generated regional benefit-per-ton estimates for ozone based on air quality modeling for the proposed Clean Power Plan. In contrast to the $PM_{2.5}$ estimates, the ozone estimates are not based on changes to annual emissions. Instead, the regional estimates (i.e., East, West, and California) correspond to NO_X emissions from U.S. EGUs during the ozone-season (May to September). Because we estimate ozone health impacts from May to September only, this approach underestimates ozone co-benefits in areas with a longer ozone season such as southern California and Texas. These estimates assume that EGU-attributable ozone formation at the regional-level is due to NOx alone. Because EGUs emit little VOC relative to NO_X emissions, it is unlikely that VOCs emitted by EGUs would contribute substantially to regional ozone formation. As noted above, all benefit-per-ton estimates have inherent limitations and should be interpreted with caution. We provide more detailed information regarding the generation of these estimates in the appendix to this chapter.

4.3.5 Estimated Health Co-Benefits Results

Tables 4-7 through 4-9 provide the regional benefit-per-ton estimates for three analysis years: 2020, 2025, and 2030. Tables 4-10 through 4-12 and 4-13 through 4-15 provide the emission reductions estimated to occur in each analysis year for the rate-based and mass-based illustrative plan approaches, respectively, by region (i.e., East, West, and California).[107] Tables 4-16 through 4-18 and 4-19 through 4-21 summarize the national monetized PM and ozone-related health co-benefits estimated to occur in each analysis year for the illustrative rate-based and mass-based plan approaches, respectively, by precursor pollutant using discount rates of 3 percent and 7 percent. Tables 4-22 through 4-24 and 4-25 through 4-27 provide national summaries of the reductions in estimated health incidences associated with the illustrative rate-based and mass-based plan approaches, respectively, in each analysis year.[108] Figure 4-1 provides a visual representation of the range of estimated $PM_{2.5}$ and ozone-related co-benefits using benefit-per-ton estimates based on concentration-response functions from different studies and expert opinion for the illustrative rate-based and mass-based plan approaches evaluated in 2025 as an illustrative analysis year. Figure 4-2 provides a breakdown of the monetized health co-benefits for the rate-based and mass-based plan approaches evaluated in 2025 as an illustrative analysis year by precursor pollutant.

[107] See Chapter 3 of this RIA for more information regarding the expected emission reductions used to calculate the health co-benefits in this chapter. Chapter 3 also provides more information regarding the illustrative plan approach.

[108] Incidence estimates were generated using the same “per ton” approach as used to generate the dollar benefit per ton values. See Appendix 4-A for details.

Table 4-7. Summary of Regional $PM_{2.5}$ Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2020 (2011$)*

Pollutant	Discount Rate	Regional		
		East	West	California
SO_2	3%	$33,000 to $75,000	$6,200 to $14,000	$95,000 to $210,000
	7%	$30,000 to $68,000	$5,600 to $13,000	$85,000 to $190,000
Directly emitted $PM_{2.5}$ (EC+OC)	3%	$140,000 to $320,000	$27,000 to $60,000	$370,000 to $830,000
	7%	$130,000 to $290,000	$24,000 to $54,000	$330,000 to $740,000
Directly emitted $PM_{2.5}$ (crustal)	3%	$23,000 to $52,000	$11,000 to $25,000	$73,000 to $160,000
	7%	$21,000 to $47,000	$9,900 to $22,000	$66,000 to $150,000
NO_X (as $PM_{2.5}$)	3%	$3,100 to $7,000	$0,670 to $1,500	$22,000 to $49,000
	7%	$2,800 to $6,300	$0,610 to $1,400	$19,000 to $44,000
NO_X (as Ozone)	N/A	$6,500 to $28,000	$2,000 to $8,900	$14,000 to $59,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for $PM_{2.5}$ and ozone. All estimates are rounded to two significant figures. The monetized co-benefits do not include reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ concentrations, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Benefit-per-ton estimates for ozone are based on ozone season NO_X emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95th percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012).

Table 4-8. Summary of Regional $PM_{2.5}$ Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2025 (2011$)*

Pollutant	Discount Rate	Regional		
		East	West	California
SO_2	3%	$37,000 to $83,000	$7,100 to $16,000	$110,000 to $240,000
	7%	$33,000 to $75,000	$6,400 to $14,000	$97,000 to $220,000
Directly emitted $PM_{2.5}$ (EC+OC)	3%	$160,000 to $360,000	$30,000 to $68,000	$410,000 to $930,000
	7%	$140,000 to $320,000	$27,000 to $61,000	$370,000 to $830,000
Directly emitted $PM_{2.5}$ (crustal)	3%	$25,000 to $58,000	$12,000 to $28,000	$82,000 to $180,000
	7%	$23,000 to $52,000	$11,000 to $25,000	$74,000 to $170,000
NO_X (as $PM_{2.5}$)	3%	$3,300 to $7,500	$0,750 to $1,700	$24,000 to $54,000
	7%	$3,000 to $6,800	$0,670 to $1,500	$22,000 to $49,000
NO_X (as Ozone)	N/A	$7,100 to $30,000	$2,300 to $10,000	$15,000 to $66,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for $PM_{2.5}$ and ozone. All estimates are rounded to two significant figures. The monetized co-benefits do not include reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ concentrations, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Benefit-per-ton estimates for ozone are based on ozone season NO_X emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95th percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012).

Table 4-9. Summary of Regional $PM_{2.5}$ Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2030 (2011$)*

Pollutant	Discount Rate	Regional		
		East	West	California
SO_2	3%	$40,000 to $89,000	$7,800 to $18,000	$120,000 to $270,000
	7%	$36,000 to $81,000	$7,100 to $16,000	$110,000 to $240,000
Directly emitted $PM_{2.5}$ (EC+OC)	3%	$170,000 to $380,000	$33,000 to $75,000	$450,000 to $1,000,000
	7%	$150,000 to $340,000	$30,000 to $68,000	$410,000 to $920,000
Directly emitted $PM_{2.5}$ (crustal)	3%	$28,000 to $62,000	$14,000 to $31,000	$90,000 to $200,000
	7%	$25,000 to $56,000	$13,000 to $28,000	$81,000 to $180,000
NO_X (as $PM_{2.5}$)	3%	$3,500 to $8,000	$0,820 to $1,900	$26,000 to $60,000
	7%	$3,200 to $7,200	$0,740 to $1,700	$24,000 to $54,000
NO_X (as Ozone)	N/A	$7,600 to $33,000	$2,600 to $11,000	$17,000 to $73,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for $PM_{2.5}$ and ozone. All estimates are rounded to two significant figures. The monetized co-benefits do not include reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ concentrations, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Benefit-per-ton estimates for ozone are based on ozone season NO_X emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95th percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012).

Table 4-10. Emission Reductions of Criteria Pollutants for the Final Emission Guidelines Rate-based Illustrative Plan Approach in 2020 (thousands of short tons)*

Region	SO_2	All-year NOx	Ozone-Season NOx
East	13	50	19
West	1	1	0
California	0	0	0
National Total	14	50	19

*All emissions shown in the table are rounded, so regional emission reductions may appear to not sum to national total. The final emissions guidelines are also expected to result in reductions in directly emitted $PM_{2.5}$, which we were not able to estimate for this RIA.

Table 4-11. Emission Reductions of Criteria Pollutants for the Final Emission Guidelines Rate-based Illustrative Plan Approach in 2025 (thousands of short tons)*

Region	SO_2	All-year NOx	Ozone-Season NOx
East	171	155	67
West	7	8	3
California	1	2	0
National Total	178	165	70

*All emissions shown in the table are rounded, so regional emission reductions may appear to not sum to national total. The final emissions guidelines are also expected to result in reductions in directly emitted $PM_{2.5}$, which we were not able to estimate for this RIA.

Table 4-12. Emission Reductions of Criteria Pollutants for the Final Emission Guidelines Rate-based Illustrative Plan Approach in 2030 (thousands of short tons)*

Region	SO_2	All-year NOx	Ozone-Season NOx
East	306	263	109
West	11	15	9
California	1	4	0
National Total	318	282	118

*All emissions shown in the table are rounded, so regional emission reductions may appear to not sum to national total. The final emissions guidelines are also expected to result in reductions in directly emitted $PM_{2.5}$, which we were not able to estimate for this RIA.

Table 4-13. Emission Reductions of Criteria Pollutants for the Final Emission Guidelines Mass-based Illustrative Plan Approach in 2020 (thousands of short tons)*

Region	SO_2	All-year NOx	Ozone-Season NOx
East	49	57	22
West	4	4	1
California	0	0	0
National Total	54	60	23

*All emissions shown in the table are rounded, so regional emission reductions may appear to not sum to national total. The final emissions guidelines are also expected to result in reductions in directly emitted $PM_{2.5}$, which we were not able to estimate for this RIA.

Table 4-14. Emission Reductions of Criteria Pollutants for the Final Emission Guidelines Mass-based Illustrative Plan Approach in 2025 (thousands of short tons)*

Region	SO_2	All-year NOx	Ozone-Season NOx
East	156	169	74
West	29	34	14
California	0	0	0
National Total	185	203	88

*All emissions shown in the table are rounded, so regional emission reductions may appear to not sum to national total. The final emissions guidelines are also expected to result in reductions in directly emitted $PM_{2.5}$, which we were not able to estimate for this RIA.

Table 4-15. Emission Reductions of Criteria Pollutants for the Final Emission Guidelines Mass-based Illustrative Plan Approach in 2030 (thousands of short tons)*

Region	SO_2	All-year NOx	Ozone-Season NOx
East	243	229	99
West	36	48	21
California	1	1	1
National Total	280	279	121

*All emissions shown in the table are rounded, so regional emission reductions may appear to not sum to national total. The final emissions guidelines are also expected to result in reductions in directly emitted $PM_{2.5}$, which we were not able to estimate for this RIA.

Table 4-16. Summary of Estimated Monetized Health Co-Benefits for the Final Emission Guidelines Rate-based Illustrative Plan Approach in 2020 (billions of 2011$) *

Pollutant	3% Discount Rate	7% Discount Rate
SO_2	$0.44 to $0.99	$0.39 to $0.89
NOx (as $PM_{2.5}$)	$0.14 to $0.33	$0.13 to $0.30
NOx (as Ozone)	$0.12 to $0.52	$0.12 to $0.52
Total	$0.70 to $1.8	$0.64 to $1.7

* All estimates are rounded to two significant figures so numbers may not sum down columns. The estimated monetized co-benefits do not include climate benefits or reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Co-benefits for $PM_{2.5}$ precursors are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95th percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012). For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

Table 4-17. Summary of Estimated Monetized Health Co-Benefits for the Final Emission Guidelines Rate-based Illustrative Plan Approach in 2025 (billions of 2011$) *

Pollutant	3% Discount Rate	7% Discount Rate
SO_2	$6.4 to $14	$5.7 to $13
NOx (as $PM_{2.5}$)	$0.56 to $1.3	$0.50 to $1.1
NOx (as Ozone)	$0.49 to $2.1	$0.49 to $2.1
Total	$7.4 to $18	$6.7 to $16

* All estimates are rounded to two significant figures so numbers may not sum down columns. The estimated monetized co-benefits do not include climate benefits or reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Co-benefits for $PM_{2.5}$ precursors are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95th percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012). For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

Table 4-18. Summary of Estimated Monetized Health Co-Benefits for the Final Emission Guidelines Rate-based Illustrative Plan Approach in 2030 (billions of 2011$) *

Pollutant	3% Discount Rate	7% Discount Rate
SO_2	$12 to $28	$11 to $25
NOx (as $PM_{2.5}$)	$1.0 to $2.3	$0.93 to $2.1
NOx (as Ozone)	$0.86 to $3.7	$0.86 to $3.7
Total	$14 to $34	$13 to $31

* All estimates are rounded to two significant figures so numbers may not sum down columns. The estimated monetized co-benefits do not include climate benefits or reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Co-benefits for $PM_{2.5}$ precursors are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95^{th} percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012). For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

Table 4-19. Summary of Estimated Monetized Health Co-Benefits for the Final Emission Guidelines Mass-based Illustrative Plan Approach in 2020 (billions of 2011$) *

Pollutant	3% Discount Rate	7% Discount Rate
SO_2	$1.7 to $3.8	$1.5 to $3.4
NOx (as $PM_{2.5}$)	$0.17 to $0.39	$0.16 to $0.36
NOx (as Ozone)	$0.14 to $0.61	$0.14 to $0.61
Total	$2.0 to $4.8	$1.8 to $4.4

* All estimates are rounded to two significant figures so numbers may not sum down columns. The estimated monetized co-benefits do not include climate benefits or reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Co-benefits for $PM_{2.5}$ precursors are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95^{th} percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012). For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

Table 4-20. Summary of Estimated Monetized Health Co-Benefits for the Final Emission Guidelines Mass-based Illustrative Plan Approach in 2025 (billions of 2011$) *

Pollutant	3% Discount Rate	7% Discount Rate
SO_2	$6.0 to $13	$5.4 to $12
NOx (as $PM_{2.5}$)	$0.58 to $1.3	$0.52 to $1.2
NOx (as Ozone)	$0.56 to $2.4	$0.56 to $2.4
Total	$7.1 to $17	$6.5 to $16

* All estimates are rounded to two significant figures so numbers may not sum down columns. The estimated monetized co-benefits do not include climate benefits or reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Co-benefits for $PM_{2.5}$ precursors are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95th percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012). For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

Table 4-21. Summary of Estimated Monetized Health Co-Benefits for the Final Emission Guidelines Mass-based Illustrative Plan Approach in 2030 (billions of 2011$) *

Pollutant	3% Discount Rate	7% Discount Rate
SO_2	$10 to $23	$9.0 to $20
NOx (as $PM_{2.5}$)	$0.87 to $2.0	$0.79 to $1.8
NOx (as Ozone)	$0.82 to $3.5	$0.82 to $3.5
Total	$12 to $28	$11 to $26

* All estimates are rounded to two significant figures so numbers may not sum down columns. The estimated monetized co-benefits do not include climate benefits or reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles and ozone. Co-benefits for $PM_{2.5}$ precursors are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. Confidence intervals are unavailable for this analysis because of the benefit-per-ton methodology. In general, the 95th percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012). For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

Table 4-22. Summary of Avoided Health Incidences from $PM_{2.5}$-Related and Ozone-Related Co-benefits for the Final Emission Guidelines Rate-based Illustrative Plan Approach in 2020*

$PM_{2.5}$-related Health Effects	
Avoided Premature Mortality	
Krewski *et al.* (2009) (adult)	64
Lepeule *et al.* (2012) (adult)	140
Woodruff *et al.* (1997) (infant)	0
Avoided Morbidity	
Emergency department visits for asthma (all ages)	34
Acute bronchitis (age 8–12)	94
Lower respiratory symptoms (age 7–14)	1,200
Upper respiratory symptoms (asthmatics age 9–11)	1,700
Minor restricted-activity days (age 18–65)	47,000
Lost work days (age 18–65)	7,900
Asthma exacerbation (age 6–18)	4,200
Hospital admissions—respiratory (all ages)	19
Hospital admissions—cardiovascular (age > 18)	23
Non-Fatal Heart Attacks (age >18)	
Peters *et al.* (2001)	73
Pooled estimate of 4 studies	8
Ozone-related Health Effects	
Avoided Premature Mortality	
Bell *et al.* (2004) (all ages)	11
Levy *et al.* (2005) (all ages)	51
Avoided Morbidity	
Hospital admissions—respiratory causes (ages > 65)	66
Hospital admissions—respiratory causes (ages < 2)	33
Emergency room visits for asthma (all ages)	37
Minor restricted-activity days (ages 18-65)	66,000
School absence days	23,000

* All estimates are rounded to whole numbers with two significant figures. Co-benefits for $PM_{2.5}$ precursors are based on regional incidence-per-ton estimates for all precursors. Co-benefits for ozone are based on ozone season NOx emissions. Confidence intervals are unavailable for this analysis because of the incidence-per-ton methodology. In general, the 95th percentile confidence interval for the health impact function alone ranges from approximately ±30 percent for mortality incidence based on Krewski *et al.* (2009) and ±46 percent based on Lepeule *et al.* (2012).

Table 4-23. Summary of Avoided Health Incidences from $PM_{2.5}$-Related and Ozone-Related Co-benefits for Final Emission Guidelines Rate-based Illustrative Plan Approach in 2025*

$PM_{2.5}$-related Health Effects	
Avoided Premature Mortality	
Krewski *et al.* (2009) (adult)	740
Lepeule *et al.* (2012) (adult)	1,700
Woodruff *et al.* (1997) (infant)	2
Avoided Morbidity	
Emergency department visits for asthma (all ages)	380
Acute bronchitis (age 8–12)	1,100
Lower respiratory symptoms (age 7–14)	14,000
Upper respiratory symptoms (asthmatics age 9–11)	20,000
Minor restricted-activity days (age 18–65)	530,000
Lost work days (age 18–65)	89,000
Asthma exacerbation (age 6–18)	48,000
Hospital admissions—respiratory (all ages)	220
Hospital admissions—cardiovascular (age > 18)	270
Non-Fatal Heart Attacks (age >18)	
Peters *et al.* (2001)	860
Pooled estimate of 4 studies	93
Ozone-related Health Effects	
Avoided Premature Mortality	
Bell *et al.* (2004) (all ages)	44
Levy *et al.* (2005) (all ages)	200
Avoided Morbidity	
Hospital admissions—respiratory causes (ages > 65)	280
Hospital admissions—respiratory causes (ages < 2)	130
Emergency room visits for asthma (all ages)	140
Minor restricted-activity days (ages 18-65)	250,000
School absence days	87,000

* All estimates are rounded to whole numbers with two significant figures. Co-benefits for $PM_{2.5}$ precursors are based on regional incidence-per-ton estimates for all precursors. Co-benefits for ozone are based on ozone season NOx emissions. Confidence intervals are unavailable for this analysis because of the incidence-per-ton methodology. In general, the 95th percentile confidence interval for the health impact function alone ranges from approximately ±30 percent for mortality incidence based on Krewski *et al.* (2009) and ±46 percent based on Lepeule *et al.* (2012).

Table 4-24. Summary of Avoided Health Incidences from $PM_{2.5}$-Related and Ozone-Related Co-Benefits for Final Emission Guidelines Rate-based Illustrative Plan Approach in 2030*

$PM_{2.5}$-related Health Effects	
Avoided Premature Mortality	
Krewski *et al.* (2009) (adult)	1,400
Lepeule *et al.* (2012) (adult)	3,200
Woodruff *et al.* (1997) (infant)	3
Avoided Morbidity	
Emergency department visits for asthma (all ages)	540
Acute bronchitis (age 8–12)	2,000
Lower respiratory symptoms (age 7–14)	26,000
Upper respiratory symptoms (asthmatics age 9–11)	37,000
Minor restricted-activity days (age 18–65)	970,000
Lost work days (age 18–65)	160,000
Asthma exacerbation (age 6–18)	90,000
Hospital admissions—respiratory (all ages)	440
Hospital admissions—cardiovascular (age > 18)	530
Non-Fatal Heart Attacks (age >18)	
Peters *et al.* (2001)	1,700
Pooled estimate of 4 studies	180
Ozone-related Health Effects	
Avoided Premature Mortality	
Bell *et al.* (2004) (all ages)	73
Levy *et al.* (2005) (all ages)	330
Avoided Morbidity	
Hospital admissions—respiratory causes (ages > 65)	500
Hospital admissions—respiratory causes (ages < 2)	200
Emergency room visits for asthma (all ages)	220
Minor restricted-activity days (ages 18-65)	400,000
School absence days	140,000

* All estimates are rounded to whole numbers with two significant figures. Co-benefits for $PM_{2.5}$ precursors are based on regional incidence-per-ton estimates for all precursors. Co-benefits for ozone are based on ozone season NOx emissions. Confidence intervals are unavailable for this analysis because of the incidence-per-ton methodology. In general, the 95th percentile confidence interval for the health impact function alone ranges from approximately ±30 percent for mortality incidence based on Krewski *et al.* (2009) and ±46 percent based on Lepeule *et al.* (2012).

Table 4-25. Summary of Avoided Health Incidences from $PM_{2.5}$-Related and Ozone-Related Co-benefits for the Final Emission Guidelines Mass-based Illustrative Plan Approach in 2020*

$PM_{2.5}$-related Health Effects	
Avoided Premature Mortality	
Krewski *et al.* (2009) (adult)	200
Lepeule *et al.* (2012) (adult)	460
Woodruff *et al.* (1997) (infant)	0
Avoided Morbidity	
Emergency department visits for asthma (all ages)	110
Acute bronchitis (age 8–12)	300
Lower respiratory symptoms (age 7–14)	3,800
Upper respiratory symptoms (asthmatics age 9–11)	5,500
Minor restricted-activity days (age 18–65)	150,000
Lost work days (age 18–65)	25,000
Asthma exacerbation (age 6–18)	13,000
Hospital admissions—respiratory (all ages)	59
Hospital admissions—cardiovascular (age > 18)	73
Non-Fatal Heart Attacks (age >18)	
Peters *et al.* (2001)	230
Pooled estimate of 4 studies	25
Ozone-related Health Effects	
Avoided Premature Mortality	
Bell *et al.* (2004) (all ages)	13
Levy *et al.* (2005) (all ages)	61
Avoided Morbidity	
Hospital admissions—respiratory causes (ages > 65)	78
Hospital admissions—respiratory causes (ages < 2)	40
Emergency room visits for asthma (all ages)	43
Minor restricted-activity days (ages 18-65)	78,000
School absence days	27,000

* All estimates are rounded to whole numbers with two significant figures. Co-benefits for $PM_{2.5}$ precursors are based on regional incidence-per-ton estimates for all precursors. Co-benefits for ozone are based on ozone season NOx emissions. Confidence intervals are unavailable for this analysis because of the incidence-per-ton methodology. In general, the 95^{th} percentile confidence interval for the health impact function alone ranges from approximately ±30 percent for mortality incidence based on Krewski *et al.* (2009) and ±46 percent based on Lepeule *et al.* (2012).

Table 4-26. Summary of Avoided Health Incidences from $PM_{2.5}$-Related and Ozone-Related Co-benefits for Final Emission Guidelines Mass-based Illustrative Plan Approach in 2025*

$PM_{2.5}$-related Health Effects	
Avoided Premature Mortality	
Krewski *et al.* (2009) (adult)	700
Lepeule *et al.* (2012) (adult)	1,600
Woodruff *et al.* (1997) (infant)	2
Avoided Morbidity	
Emergency department visits for asthma (all ages)	350
Acute bronchitis (age 8–12)	1,000
Lower respiratory symptoms (age 7–14)	13,000
Upper respiratory symptoms (asthmatics age 9–11)	19,000
Minor restricted-activity days (age 18–65)	500,000
Lost work days (age 18–65)	84,000
Asthma exacerbation (age 6–18)	46,000
Hospital admissions—respiratory (all ages)	210
Hospital admissions—cardiovascular (age > 18)	260
Non-Fatal Heart Attacks (age >18)	
Peters *et al.* (2001)	810
Pooled estimate of 4 studies	88
Ozone-related Health Effects	
Avoided Premature Mortality	
Bell *et al.* (2004) (all ages)	51
Levy *et al.* (2005) (all ages)	230
Avoided Morbidity	
Hospital admissions—respiratory causes (ages > 65)	320
Hospital admissions—respiratory causes (ages < 2)	150
Emergency room visits for asthma (all ages)	160
Minor restricted-activity days (ages 18-65)	290,000
School absence days	100,000

* All estimates are rounded to whole numbers with two significant figures. Co-benefits for $PM_{2.5}$ precursors are based on regional incidence-per-ton estimates for all precursors. Co-benefits for ozone are based on ozone season NOx emissions. Confidence intervals are unavailable for this analysis because of the incidence-per-ton methodology. In general, the 95th percentile confidence interval for the health impact function alone ranges from approximately ±30 percent for mortality incidence based on Krewski *et al.* (2009) and ±46 percent based on Lepeule *et al.* (2012).

Table 4-27. Summary of Avoided Health Incidences from $PM_{2.5}$-Related and Ozone-Related Co-Benefits for Final Emission Guidelines Mass-based Illustrative Plan Approach in 2030*

$PM_{2.5}$-related Health Effects	
Avoided Premature Mortality	
Krewski *et al.* (2009) (adult)	1,200
Lepeule *et al.* (2012) (adult)	2,600
Woodruff *et al.* (1997) (infant)	2
Avoided Morbidity	
Emergency department visits for asthma (all ages)	440
Acute bronchitis (age 8–12)	1,600
Lower respiratory symptoms (age 7–14)	21,000
Upper respiratory symptoms (asthmatics age 9–11)	30,000
Minor restricted-activity days (age 18–65)	790,000
Lost work days (age 18–65)	130,000
Asthma exacerbation (age 6–18)	74,000
Hospital admissions—respiratory (all ages)	360
Hospital admissions—cardiovascular (age > 18)	430
Non-Fatal Heart Attacks (age >18)	
Peters *et al.* (2001)	1,400
Pooled estimate of 4 studies	150
Ozone-related Health Effects	
Avoided Premature Mortality	
Bell *et al.* (2004) (all ages)	70
Levy *et al.* (2005) (all ages)	320
Avoided Morbidity	
Hospital admissions—respiratory causes (ages > 65)	470
Hospital admissions—respiratory causes (ages < 2)	200
Emergency room visits for asthma (all ages)	210
Minor restricted-activity days (ages 18-65)	380,000
School absence days	130,000

* All estimates are rounded to whole numbers with two significant figures. Co-benefits for $PM_{2.5}$ precursors are based on regional incidence-per-ton estimates for all precursors. Co-benefits for ozone are based on ozone season NOx emissions. Confidence intervals are unavailable for this analysis because of the incidence-per-ton methodology. In general, the 95th percentile confidence interval for the health impact function alone ranges from approximately ±30 percent for mortality incidence based on Krewski *et al.* (2009) and ±46 percent based on Lepeule *et al.* (2012).

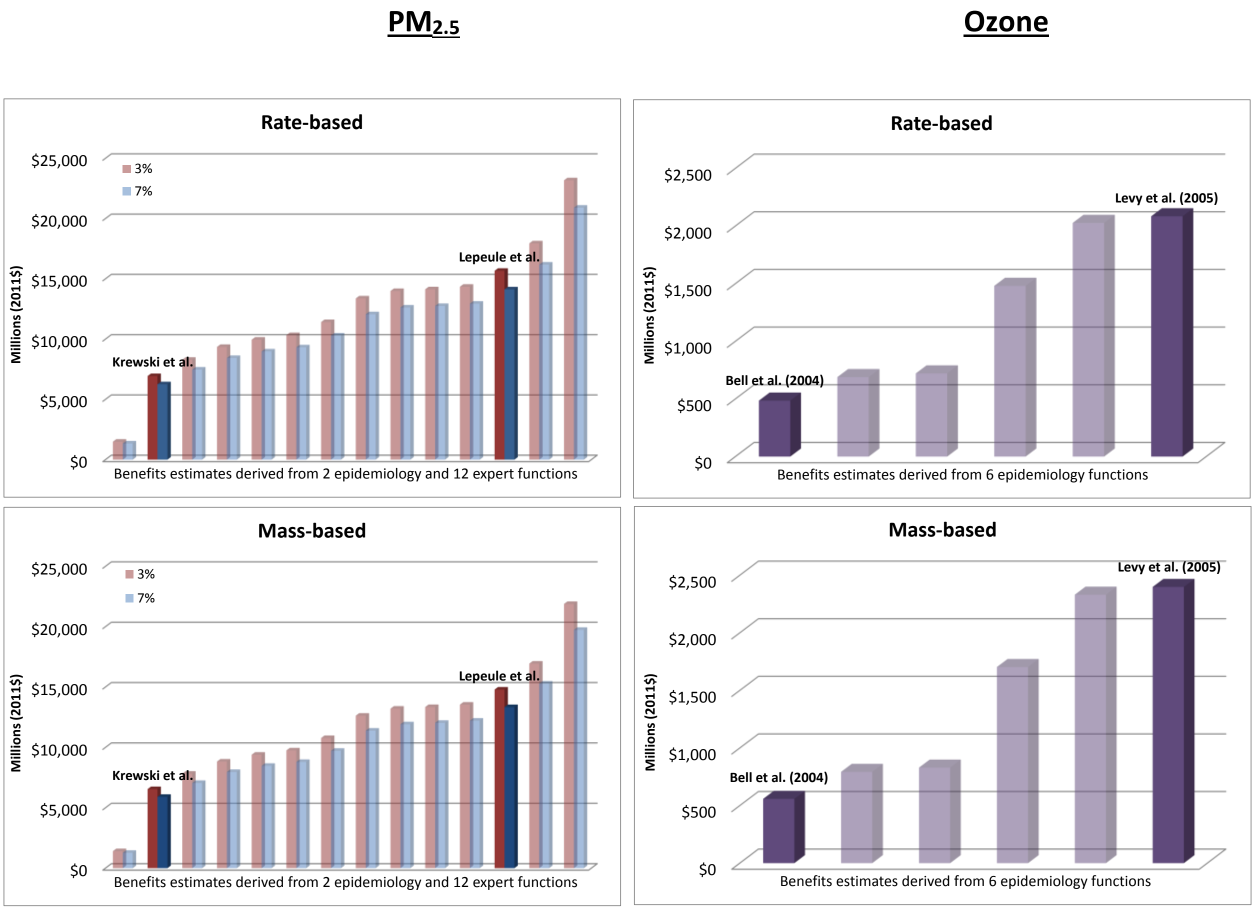


Figure 4-1. Monetized Health Co-benefits of Rate-based and Mass-based Illustrative Plan Approaches for the Final Emission Guidelines in 2025 *

*The $PM_{2.5}$ graphs show the estimated $PM_{2.5}$ co-benefits at discount rates of 3% and 7% using effect coefficients derived from the Krewski *et al.* (2009) study and the Lepeule *et al.* (2012) study, as well as 12 effect coefficients derived from EPA's expert elicitation on PM mortality (Roman *et al.*, 2008). The results shown are not the direct results from the studies or expert elicitation; rather, the estimates are based in part on the concentration-response functions provided in those studies. The ozone graphs show the estimated ozone co-benefits derived from six ozone mortality studies (i.e., Bell *et al.* (2004), Schwartz (2005), Huang *et al.* (2005), Bell *et al.* (2005), Levy *et al.* (2005), and Ito *et al.* (2005). Ozone co-benefits occur in the analysis year, so they are the same for all discount rates. These estimates do not include benefits from reductions in CO2. The monetized co-benefits do not include climate benefits from changes in NO_2 and SO_2or reduced health effects from direct exposure to NO_2, SO_2, ecosystem effects, or visibility impairment. For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

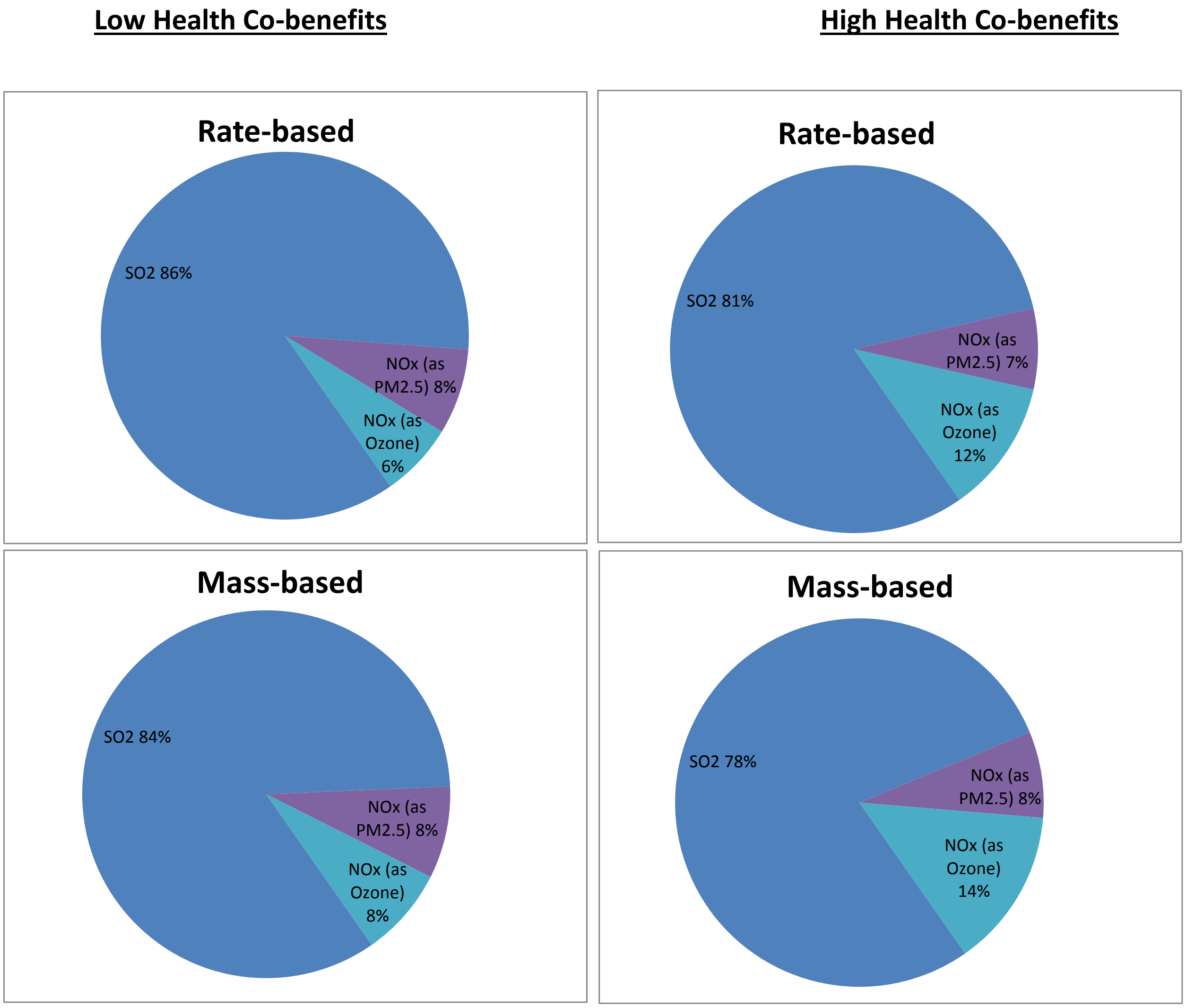


Figure 4-2. Breakdown of Monetized Health Co-benefits by Precursor Pollutant at a 3% Discount Rate for Rate-based and Mass-based Illustrative Plan Approaches for the Final Emission Guidelines in 2025*

* "Low Health Co-benefits" refers to the combined health co-benefits estimated using the Bell *et al.* (2004) mortality study for ozone with the Krewski *et al.* (2009) mortality study for $PM_{2.5}$. "High Health Co-benefits" refers to the combined health co-benefits estimated using the Levy *et al.* (2005) mortality study for ozone with the Lepeule *et al.* (2012) mortality study for $PM_{2.5}$. For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 10 percent of total monetized health co-benefits across all scenarios and years.

4.3.6 Characterization of Uncertainty in the Estimated Health Co-benefits

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty. This analysis is no exception. This analysis includes many data sources as inputs, including emission inventories, air quality data from models (with their associated parameters and inputs), population data, population estimates, health effect estimates from epidemiology studies, economic data for monetizing co-benefits, and assumptions regarding the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain and would affect the estimate of co-benefits. When the uncertainties from each stage of the analysis are compounded, even small uncertainties can have large effects on the total quantified benefits. In addition, the use of the benefit-per-ton approach adds additional uncertainties beyond those for analyses based directly on air quality modeling. Therefore, the estimates of co-benefits in each analysis year should be viewed as representative of the general magnitude of co-benefits of the illustrative plan approach, rather than the actual co-benefits anticipated from implementing the final emission guidelines.

This RIA does not include the type of detailed uncertainty assessment found in the PM NAAQS RIA (U.S. EPA, 2012a) or the Ozone NAAQS RIA (U.S. EPA, 2008b) because we lack the necessary air quality modeling input and/or monitoring data to run the benefits model. However, the results of the quantitative and qualitative uncertainty analyses presented in the PM NAAQS RIA and Ozone NAAQS RIA can provide some information regarding the uncertainty inherent in the estimated co-benefits results presented in this analysis. For example, sensitivity analyses conducted for the PM NAAQS RIA indicate that alternate cessation lag assumptions could change the estimated $PM_{2.5}$-related mortality co-benefits discounted at 3 percent by between 10 percent and –27 percent and that alternative income growth adjustments could change the $PM_{2.5}$-related mortality co-benefits by between 33 percent and −14 percent. Although we generally do not calculate confidence intervals for benefit-per-ton estimates and they can provide an incomplete picture about the overall uncertainty in the benefits estimates, the PM NAAQS RIA provides an indication of the random sampling error in the health impact and economic valuation functions using Monte Carlo methods. In general, the 95th percentile confidence interval for monetized $PM_{2.5}$ benefits ranges from approximately -90 percent to +180 percent of the central estimates based on Krewski *et al.* (2009) and Lepeule *et al.* (2012). The 95th percentile confidence interval for the health impact function alone ranges from approximately ±30 percent for mortality incidence based on Krewski *et al.* (2009) and ±46 percent based on Lepeule *et al.* (2012).

Unlike RIAs for which the EPA conducts scenario-specific air quality modeling, we do not have information on the specific location of the air quality changes associated with the final emission guidelines. As such, it is not feasible to estimate the proportion of co-benefits occurring in different locations, such as designated nonattainment areas. Instead, we applied benefit-per-ton estimates, which reflect specific geographic patterns of emissions reductions and specific air quality and benefits modeling assumptions. For example, these estimates may not 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 co-benefits of controlling PM and ozone precursors. Use of these benefit-per-ton values to estimate co-benefits may lead to higher or lower benefit estimates than if co-benefits were calculated based on direct air quality modeling. Great care should be taken in applying these estimates to emission reductions occurring in any specific location, as these are all based on a broad emission reduction scenario and therefore represent average benefits-per-ton over the entire region. The benefit-per-ton for emission reductions in specific locations may be very different than the estimates presented here. To the extent that the geographic distribution of the emissions reductions achieved by implementing the final emission guidelines is different than the emissions in the air quality modeling of the proposal, the co-benefits may be underestimated or overestimated.

Our estimate of the total monetized co-benefits is based on the EPA's interpretation of the best available scientific literature and methods and supported by the SAB-HES and the National Academies of Science (NRC, 2002). Below are key assumptions underlying the estimates for $PM_{2.5}$-related premature mortality, which accounts for 98 percent of the monetized $PM_{2.5}$ health co-benefits.

1. We assume that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ varies considerably in composition across sources, but the scientific evidence is not yet sufficient to allow differentiation of effect estimates by particle type. The PM ISA concluded that "many constituents of $PM_{2.5}$ can be linked with multiple health effects, and the evidence is not yet sufficient to allow differentiation of those constituents or sources that are more closely related to specific outcomes" (U.S. EPA, 2009b).

2. We assume that the health impact function for fine particles is log-linear without a threshold. Thus, the estimates include health co-benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5}$, including both areas that do not meet the fine

particle standard and those areas that are in attainment, down to the lowest modeled concentrations.

3. We assume that there is a “cessation” lag between the change in PM exposures and the total realization of changes in mortality effects. Specifically, we assume that some of the incidences of premature mortality related to $PM_{2.5}$ exposures occur in a distributed fashion over the 20 years following exposure based on the advice of the SAB-HES (U.S. EPA-SAB, 2004c), which affects the valuation of mortality co-benefits at different discount rates.

In general, we are more confident in the magnitude of the risks we estimate from simulated $PM_{2.5}$ concentrations that coincide with the bulk of the observed PM concentrations in the epidemiological studies that are used to estimate the benefits. Likewise, we are less confident in the risk we estimate from simulated $PM_{2.5}$ concentrations that fall below the bulk of the observed data in these studies. Concentration benchmark analyses (e.g., lowest measured level [LML], one standard deviation below the mean of the air quality data in the study, etc.) allow readers to determine the portion of population exposed to annual mean $PM_{2.5}$ levels at or above different concentrations, which provides some insight into the level of uncertainty in the estimated $PM_{2.5}$ mortality benefits. In this analysis, we apply two concentration benchmark approaches (LML and one standard deviation below the mean) that have been incorporated into recent RIAs and the EPA’s *Policy Assessment for Particulate Matter* (U.S. EPA, 2011d). There are uncertainties inherent in identifying any particular point at which our confidence in reported associations becomes appreciably less, and the scientific evidence provides no clear dividing line. However, the EPA does not view these concentration benchmarks as a concentration threshold below which we would not quantify health co-benefits of air quality improvements.[109] Rather, the co-benefits estimates reported in this RIA are the best estimates because they reflect the full range of air quality concentrations associated with the emission reduction strategies. The PM ISA concluded that the scientific evidence collectively is sufficient to conclude that the relationship between long-term $PM_{2.5}$ exposures and mortality is causal and that overall the studies support

[109] For a summary of the scientific review statements regarding the lack of a threshold in the $PM_{2.5}$-mortality relationship, see the TSD entitled *Summary of Expert Opinions on the Existence of a Threshold in the Concentration-Response Function for $PM_{2.5}$-related Mortality* (U.S. EPA, 2010b).

the use of a no-threshold log-linear model to estimate PM-related long-term mortality (U.S. EPA, 2009b).

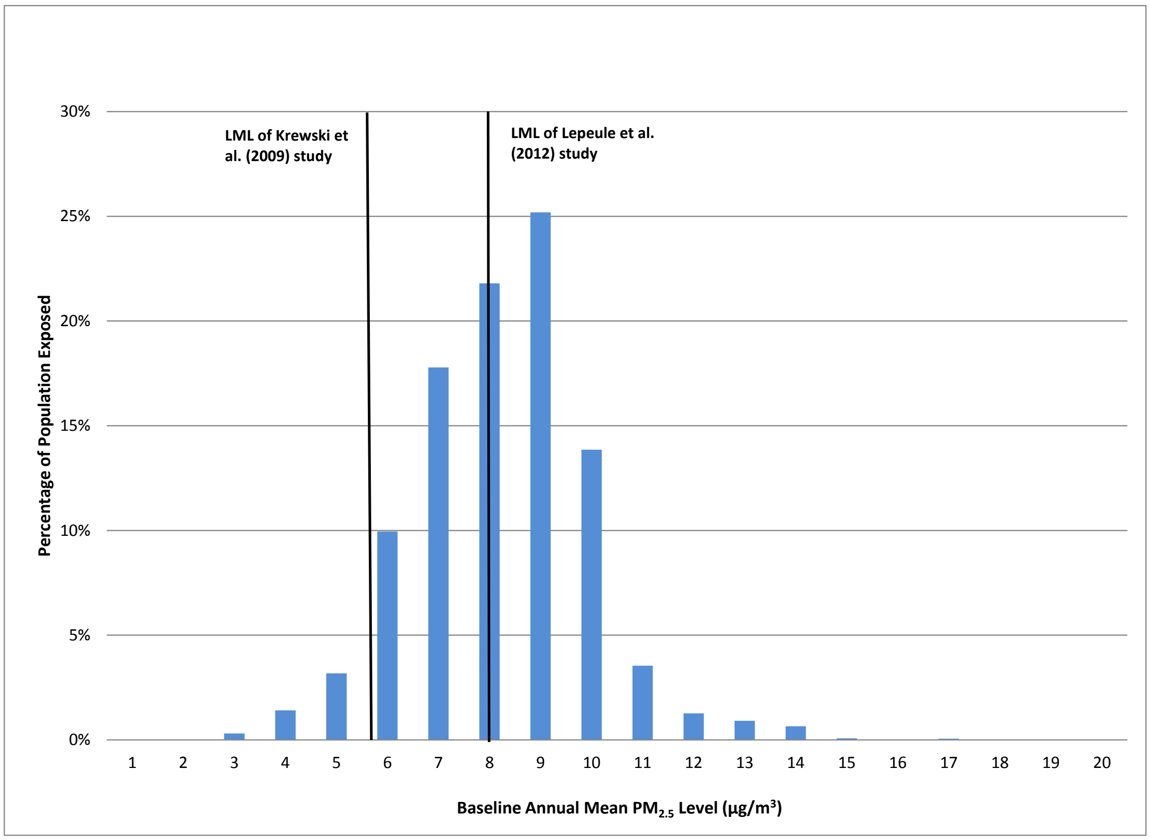
For this analysis, policy-specific air quality data is not available, and the plan scenarios are illustrative of what states may choose to do. However, we believe that it is still important to characterize the distribution of exposure to baseline concentrations. As a surrogate measure of mortality impacts, we provide the percentage of the population exposed at each $PM_{2.5}$ concentration in the baseline of the air quality modeling used to calculate the benefit-per-ton estimates for this final RIA using 12 km grid cells across the contiguous U.S. It is important to note that baseline exposure is only one parameter in the health impact function, along with baseline incidence rates population and change in air quality. In other words, the percentage of the population exposed to air pollution below the LML is not the same as the percentage of the population experiencing health impacts as a result of a specific emission reduction policy. The most important aspect, which we are unable to quantify without rule-specific air quality modeling, is the shift in exposure anticipated by implementing the final emission guidelines. Therefore, caution is warranted when interpreting the LML assessment in this RIA because these results are not consistent with results from RIAs that had air quality modeling.

Table 4-28 provides the percentage of the population exposed above and below two concentration benchmarks (i.e., LML and one standard deviation below the mean) in the Clean Power Plan proposal modeling. Figure 4-3 shows a bar chart of the percentage of the population exposed to various air quality levels in the proposal modeling, and Figure 4-4 shows a cumulative distribution function of the same data. Both figures identify the LML for each of the major cohort studies.

Table 4-28. Population Exposure in the Clean Power Plan Proposal Option 1 State Scenario Modeling (used to generate the benefit-per-ton estimates) Above and Below Various Concentrations Benchmarks in the Underlying Epidemiology Studies*

Epidemiology Study	Below 1 Standard Deviation. Below AQ Mean	At or Above 1 Standard Deviation Below AQ Mean	Below LML	At or Above LML
Krewski *et al.* (2009)	3%	97%	12%	88%
Lepeule *et al.* (2012)	N/A	N/A	54%	46%

*One standard deviation below the mean is equivalent to the middle of the range between the 10th and 25th percentile. For Krewski, the LML is 5.8 µg/m^3 and one standard deviation below the mean is 11.0 µg/m^3. For Lepeule *et al.*, the LML is 8 µg/m^3 and we do not have the data for one standard deviation below the mean. It is important to emphasize that although we have lower levels of confidence in levels below the LML for each study, the scientific evidence does not support the existence of a level below which health effects from exposure to $PM_{2.5}$ do not occur.

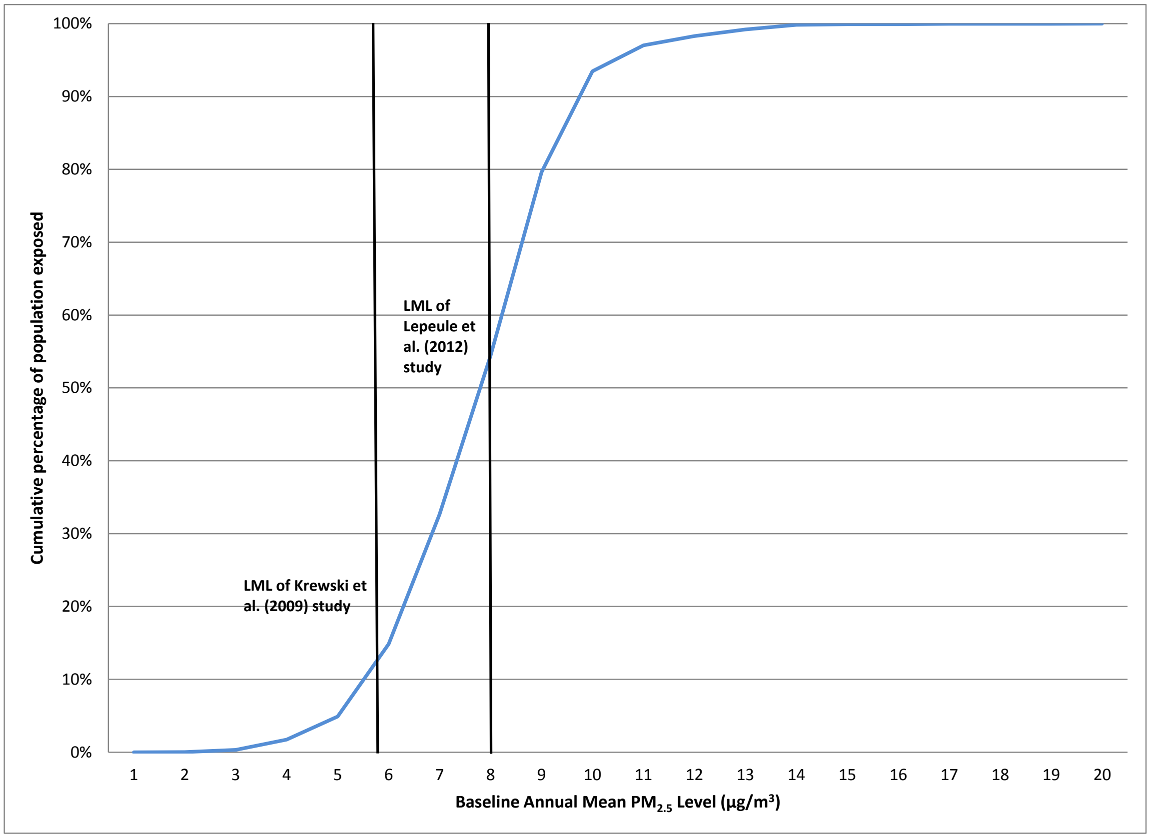


Among the populations exposed to $PM_{2.5}$ in the baseline:

88% are exposed to $PM_{2.5}$ levels at or above the LML of the Krewski *et al.* (2009) study

46% are exposed to $PM_{2.5}$ levels at or above the LML of the Lepeule *et al.* (2012) study

Figure 4-3. Percentage of Adult Population (age 30+) by Annual Mean $PM_{2.5}$ Exposure in the Option 1 State Scenario Clean Power Plan Proposal Modeling (used to generate the benefit-per-ton estimates)



Among the populations exposed to $PM_{2.5}$ in the baseline:

88% are exposed to $PM_{2.5}$ levels at or above the LML of the Krewski *et al.* (2009) study

46% are exposed to $PM_{2.5}$ levels at or above the LML of the Lepeule *et al.* (2012) study

Figure 4-4. Cumulative Distribution of Adult Population (age 30+) by Annual Mean $PM_{2.5}$ Exposure in the Option 1 State Scenario Clean Power Plan Proposal Modeling (used to generate the benefit-per-ton estimates)

4.4 Combined Climate Benefits and Health Co-Benefits Estimates

In this analysis, we were able to monetize the estimated benefits associated with the decreased emissions of CO_2 and co-benefits of reduced exposure to $PM_{2.5}$ and ozone, but we were unable to monetize the co-benefits associated with reducing exposure to mercury, carbon monoxide, SO_2, and NO_2, as well as ecosystem effects and visibility impairment. In addition, there are expected to be unquantified health and welfare impacts associated with changes in hydrogen chloride. Specifically, we estimated combinations of climate benefits at discount rates of 5 percent, 3 percent, 2.5 percent, and 3 percent (95th percentile) (as recommended by the interagency working group), and health co-benefits at discount rates of 3 percent and 7 percent (as recommended by the EPA's *Guidelines for Preparing Economic Analyses* [U.S. EPA, 2014] and OMB's *Circular A-4* [OMB, 2003]).

Different discount rates are applied to SC-CO_2 than to the health co-benefit estimates because CO_2 emissions are long-lived and subsequent damages occur over many years. Moreover, several rates are applied to SC-CO_2 because the literature shows that it is sensitive to assumptions about discount rate and because no consensus exists on the appropriate rate to use in an intergenerational context. The SC-CO_2 interagency group centered its attention on the 3 percent discount rate but emphasized the importance of considering all four SC-CO_2 estimates.[110] The EPA has evaluated the range of potential impacts by combining all SC-CO_2 values with health co-benefits values at the 3 percent and 7 percent discount rates. Combining the 3 percent SC-CO_2 values with the 3 percent health benefit values assumes that there is no difference in discount rates between intragenerational and intergenerational impacts.

Tables 4-29 through 4-31 provide the combined climate and health benefits for the illustrative plan approaches evaluated for each analysis year: 2020, 2025, and 2030. Figure 4-5 shows the breakdown of the monetized benefits by pollutant for the illustrative plan approaches evaluated in 2025 as an illustrative analysis year using a 3 percent discount rate for both climate and health benefits.

[110] See the 2010 SCC TSD. Docket ID EPA-HQ-OAR-2009-0472-114577 or http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf for details.

Table 4-29. Combined Climate Benefits and Health Co-Benefits for Final Emission Guidelines in 2020 (billions of 2011$)*

SCC Discount Rate	Climate Benefits Only	Climate and Health Benefits (Discount Rate Applied to Health Co-Benefits) 3%	7%
Rate-based	**69**	**million short tons CO_2**	
5%	$0.80	$1.5 to $2.6	$1.4 to $2.5
3%	$2.8	$3.5 to $4.6	$3.5 to $4.5
2.5%	$4.1	$4.9 to $6.0	$4.8 to $5.9
3% (95th percentile)	$8.2	$8.9 to $10	$8.9 to $9.9
Mass-based	**82**	**million short tons CO_2**	
5%	$0.94	$2.9 to $5.7	$2.8 to $5.3
3%	$3.3	$5.3 to $8.1	$5.1 to $7.7
2.5%	$4.9	$6.9 to 9.7	$6.7 to $9.3
3% (95th percentile)	$9.6	$12 to $14	$11 to $14

*All estimates are rounded to two significant figures. Climate benefits are based on reductions in CO_2 emissions. Co-benefits are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. The health co-benefits reflect the sum of the $PM_{2.5}$ and ozone co-benefits and reflect the range based on adult mortality functions (e.g., from Krewski *et al.* (2009) with Bell *et al.* (2004) to Lepeule *et al.* (2012) with Levy *et al.* (2005)). The monetized health co-benefits do not include reduced health effects from directly emitted $PM_{2.5}$, direct exposure to NO_2, SO_2, and HAP; ecosystem effects; or visibility impairment.

Table 4-30. Combined Climate Benefits and Health Co-Benefits for Final Emission Guidelines in 2025 (billions of 2011$)*

SCC Discount Rate	Climate Benefits Only	Climate and Health Benefits (Discount Rate Applied to Health Co-Benefits) 3%	7%
Rate-based	**232**	**million short tons CO_2**	
5%	$3.1	$11 to $21	$9.9 to $19
3%	$10	$18 to $28	$17 to $26
2.5%	$15	$23 to $33	$22 to $31
3% (95th percentile)	$31	$38 to $49	$38 to $47
Mass-based	**264**	**million short tons CO_2**	
5%	$3.6	$11 to $21	$10 to $19
3%	$12	$19 to $29	$18 to $27
2.5%	$17	$24 to $34	$24 to $33
3% (95th percentile)	$35	$42 to $52	$42 to $51

*All estimates are rounded to two significant figures. Climate benefits are based on reductions in CO_2 emissions. Co-benefits are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. The health co-benefits reflect the sum of the $PM_{2.5}$ and ozone co-benefits and reflect the range based on adult mortality functions (e.g., from Krewski *et al.* (2009) with Bell *et al.* (2004) to Lepeule *et al.* (2012) with Levy *et al.* (2005)). The monetized health co-benefits do not include reduced health effects from directly emitted $PM_{2.5}$, direct exposure to NO_2, SO_2, and HAP; ecosystem effects; or visibility impairment.

Table 4-31. Combined Climate Benefits and Health Co-Benefits for Final Emission Guidelines in 2030 (billions of 2011$)*

SCC Discount Rate	Climate Benefits Only	Climate and Health Benefits (Discount Rate Applied to Health Co-Benefits) 3%	7%
Rate-based	**415**	**million short tons CO_2**	
5%	$6.4	$21 to $40	$19 to $37
3%	$20	$34 to $54	$33 to $51
2.5%	$29	$43 to $63	$42 to $60
3% (95th percentile)	$61	$75 to $95	$74 to $92
Mass-based	**413**	**million short tons CO_2**	
5%	$6.4	$18 to $34	$17 to $32
3%	$20	$32 to $48	$31 to $46
2.5%	$29	$41 to $57	$40 to $55
3% (95th percentile)	$60	$72 to $89	$71 to $86

*All estimates are rounded to two significant figures. Climate benefits are based on reductions in CO_2 emissions. Co-benefits are based on regional benefit-per-ton estimates. Co-benefits for ozone are based on ozone season NOx emissions. Ozone co-benefits occur in analysis year, so they are the same for all discount rates. The health co-benefits reflect the sum of the $PM_{2.5}$ and ozone co-benefits and reflect the range based on adult mortality functions (e.g., from Krewski *et al.* (2009) with Bell *et al.* (2004) to Lepeule *et al.* (2012) with Levy *et al.* (2005)). The monetized health co-benefits do not include reduced health effects from directly emitted $PM_{2.5}$, direct exposure to NO_2, SO_2, and HAP; ecosystem effects; or visibility impairment.

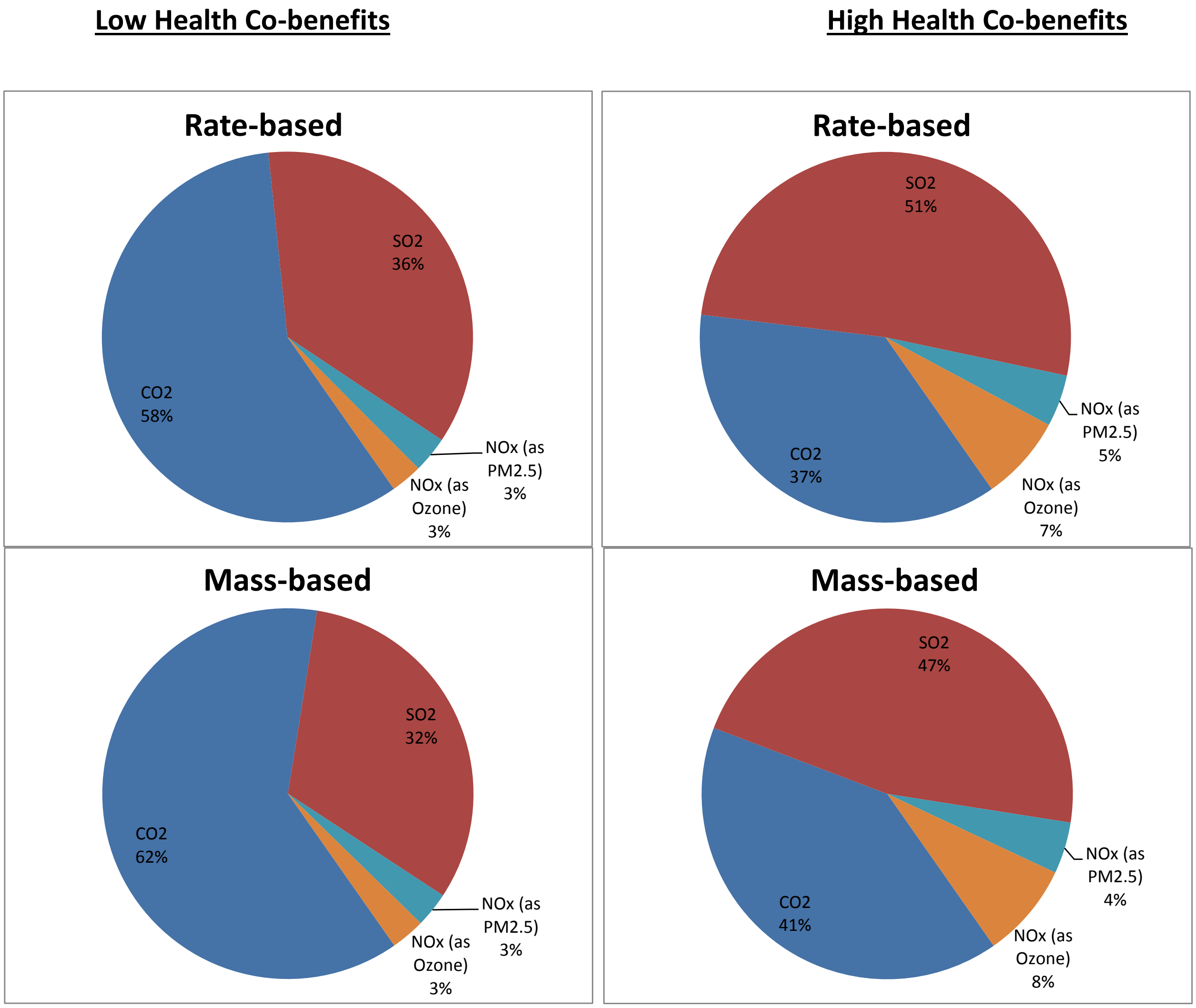


Figure 4-5. Breakdown of Combined Monetized Climate and Health Co-benefits of Final Emission Guidelines in 2025 for Rate-based and Mass-based Illustrative Plan Approaches and Pollutants (3% discount rate)*

* "Low Health Co-benefits" refers to the combined health co-benefits estimated using the Bell *et al.* (2004) mortality study for ozone with the Krewski *et al.* (2009) mortality study for $PM_{2.5}$. "High Health Co-benefits" refers to the combined health co-benefits estimated using the Levy *et al.* (2005) mortality study for ozone with the Lepeule *et al.* (2012) mortality study for $PM_{2.5}$. For this RIA, we did not estimate changes in emissions of directly emitted particles. As a result, quantified $PM_{2.5}$ related benefits are underestimated by a relatively small amount. In the proposal RIA, the benefits from reductions in directly emitted $PM_{2.5}$ were less than 8 percent of total monetized benefits across all scenarios and years.

4.5 Unquantified Co-benefits

The monetized co-benefits estimated in this RIA reflect a subset of co-benefits attributable to the health effect reductions associated with ambient fine particles and ozone. Data, time, and

Appendix 4A: Generating Regional Benefit-per-Ton Estimates

The purpose of this appendix is to provide additional detail regarding the generation of the benefit-per-ton estimates applied in Chapter 4 of this Regulatory Impact Analysis (RIA). Specifically, this appendix describes the methods for generating benefit-per-ton estimates by region for the contiguous U.S. for $PM_{2.5}$ and ozone precursors emitted by the electrical generating unit (EGU) sector in the Final Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units (hereafter referred to as the "final emission guidelines" or "Clean Power Plan Final Rule").

4A.1 Overview of Benefit-per-Ton Estimates

As described in the *Technical Support Document: Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors* (U.S. EPA, 2013), the general procedure for calculating average benefit-per-ton coefficients generally follows three steps. As an example, in order to calculate regional average benefit-per-ton estimates for the key precursor pollutants emitted from EGU sources, we:

1. Use air quality modeling to predict changes in ambient concentrations of primary $PM_{2.5}$, nitrate, sulfate, and ozone at a 12km^2 grid resolution across the contiguous U.S. that are attributable to the proposed Clean Power Plan.

2. For each grid cell, estimate the health impacts, and the economic value of these impacts, associated with the attributable ambient concentrations using the environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE v1.1).[120,121] Aggregate those impacts and economic values to the three regions of East, West, and California.

3. Divide the regional health impacts attributable to each precursor, and the regional monetary value of these impacts, by the amount of associated regional precursor emissions. That is, directly emitted $PM_{2.5}$ benefits are divided by directly emitted $PM_{2.5}$ emissions, sulfate benefits are divided by SO_2 emissions, nitrate benefits are divided by NO_X emissions, and ozone benefits are divided by ozone-season NO_X emissions.

[120] When estimating these impacts we apply effect coefficients that relate changes in total $PM_{2.5}$ mass to the risk of adverse health outcomes; we do not apply effect coefficients that are differentiated by $PM_{2.5}$ species.
[121] Previous RIAs have used earlier versions of the BenMAP software. BenMAP-CE v1.1 provides results consistent with earlier versions of BenMAP and is available for download at http://www.epa.gov/air/benmap/.

4A.2 Air Quality Modeling for the Proposed Clean Power Plan

The EPA ran the Comprehensive Model with Extensions (CAMx) photochemical model (ENVIRON, 2014) to predict ozone and $PM_{2.5}$ concentrations for the following emissions scenarios: a 2011 base year, a 2025 base case, and the 2025 proposed Clean Power Plan (Option 1 State) scenario. Each of the CAMx model simulations was performed for a nationwide modeling domain[122] using a full year of meteorological conditions for 2011. The modeling for 2011 was used as the anchor point for projecting ozone and annual $PM_{2.5}$ concentration values for the 2025 base case and for the 2025 Clean Power Plan proposal scenario using methodologies consistent with the EPA's air quality modeling guidance (U.S. EPA, 2007). The air quality modeling results for the 2025 base case served as the baseline for gauging the future year impacts on ozone and annual $PM_{2.5}$ of the Clean Power Plan proposal scenario. The 2025 base case reflects emissions reductions between 2011 and 2025 that are expected to result from regional and national rules including the Clean Air Interstate Rule (CAIR), the Mercury and Air Toxics Standards (MATS), mobile source rules up through Tier-3, and various state emissions control programs and consent decrees. The methods for estimating the EGU emissions for the proposal are described in Chapter 3 of the RIA for the Clean Power Plan proposal (U.S. EPA, 2014). State total annual EGU emissions for NO_X and SO_2 for each of the scenarios modeled are provided in Tables 4A-1 and 4A-2, respectively. The data indicate that, overall nationwide, EGU SO_2 and NO_X emissions with proposed Option 1 (state) would be about 28% lower than the 2025 base case.

[122] The modeling domain (i.e., region modeled) includes all of the lower 48 states plus adjacent portions of Canada and Mexico) at a spatial resolution of 12 km.

Table 4A-1. State Total Annual EGU Emissions for NO_X for the 2011 Base Year, 2025 Base Case, and 2025 Clean Power Plan Proposal (Option 1 State) (in thousands of tons)

State	2011 Base Year	2025 Base Case	2025 Clean Power Plan Proposal (Option 1 State)
Alabama	63	38	19
Arizona	35	17	4
Arkansas	38	43	9
California	6	33	28
Colorado	51	29	21
Connecticut	1	1	1
Delaware	4	1	1
Florida	61	52	15
Georgia	54	33	18
Idaho	-	1	0
Illinois	73	38	32
Indiana	121	97	90
Iowa	40	24	24
Kansas	44	28	27
Kentucky	92	59	74
Louisiana	47	18	14
Maine	2	4	2
Maryland	19	11	11
Massachusetts	5	2	1
Michigan	75	73	51
Minnesota	32	27	13
Mississippi	26	15	3
Missouri	66	61	58
Montana	20	16	15
Nebraska	37	38	35
Nevada	7	5	3
New Hampshire	4	1	0
New Jersey	6	7	2
New Mexico	23	7	6
New York	22	11	7
North Carolina	46	35	23
North Dakota	51	51	48
Ohio	104	63	60
Oklahoma	82	52	26
Oregon	5	3	3
Pennsylvania	149	106	71
Rhode Island	0	0	1
South Carolina	25	13	8
South Dakota	11	13	8
Tennessee	27	16	13
Texas	146	144	64
Tribal Data	65	33	33
Utah	51	49	33
Vermont	0	0	0

State	2011 Base Year	2025 Base Case	2025 Clean Power Plan Proposal (Option 1 State)
Virginia	38	21	12
Washington	7	3	2
West Virginia	58	49	46
Wisconsin	32	19	11
Wyoming	53	50	38
National Total	2,024	1,508	1,084

Table 4A-2. State Total Annual EGU Emissions for SO_2 for the 2011 Base Year, 2025 Base Case, and 2025 Clean Power Plan Proposal (Option 1 State) (in thousands of tons)

State	2011 Base Year	2025 Base Case	2025 Clean Power Plan Proposal (Option 1 State)
Alabama	186	79	45
Arizona	28	18	4
Arkansas	74	30	5
California	1	4	4
Colorado	45	15	10
Connecticut	1	-	-
Delaware	11	1	1
Florida	95	70	7
Georgia	187	37	12
Idaho	-	0	0
Illinois	227	45	48
Indiana	382	126	121
Iowa	100	18	18
Kansas	39	15	15
Kentucky	246	109	119
Louisiana	93	14	11
Maine	1	1	1
Maryland	32	5	9
Massachusetts	23	1	0
Michigan	228	122	95
Minnesota	40	21	12
Mississippi	43	10	3
Missouri	205	80	76
Montana	19	18	17
Nebraska	73	25	24
Nevada	5	1	1
New Hampshire	24	0	0
New Jersey	5	7	1
New Mexico	6	4	4
New York	41	4	2
North Carolina	78	36	33
North Dakota	93	15	14

State	2011 Base Year	2025 Base Case	2025 Clean Power Plan Proposal (Option 1 State)
Ohio	594	105	102
Oklahoma	96	21	6
Oregon	13	1	1
Pennsylvania	338	67	47
Rhode Island	0	-	-
South Carolina	68	19	12
South Dakota	11	11	7
Tennessee	120	38	31
Texas	426	149	48
Tribal Data	18	19	19
Utah	22	14	10
Vermont	0	0	0
Virginia	75	8	4
Washington	1	1	1
West Virginia	103	78	47
Wisconsin	92	17	11
Wyoming	55	23	17
National Total	4,665	1,504	1,077

As indicated above, the air quality modeling was used to project gridded ozone and annual $PM_{2.5}$ concentrations at the $12km^2$ resolution for the 2025 base case and the Clean Power Plan proposal scenario modeled for this analysis. The air quality modeling results were combined with monitored ozone and PM2.5 data to create projected spatial fields of annual $PM_{2.5}$ and seasonal mean (May through September) 8-hour daily maximum ozone for the 2025 base case and for the proposal scenario. These spatial fields were then used as inputs to estimate the health co-benefits of the proposed Clean Power Plan as described below.

4A.3 Regional $PM_{2.5}$ Benefit-per-Ton Estimates for EGUs Derived from Air Quality Modeling of the Proposed Clean Power Plan

After estimating the $12km^2$ resolution $PM_{2.5}$ benefits for each of the analysis years applied in this RIA (i.e., 2020, 2025, and 2030), we aggregated the benefits results regionally (i.e., East, West, and California), as shown in Figure 4A-1.[123] While a small percentage of benefits from emissions reductions in a particular region may occur in one of the other regions, we selected each region to minimize this percentage. Thus, the benefits per ton in each region

[123] This aggregation is identified as the shapefile “Report Regions” in BenMAP’s grid definitions.

will represent well the match between where the emissions reductions and air quality benefits are occurring. Due to the low emissions of SO_2, NO_X, and directly emitted particles from EGUs in California and the high population density, we separated out California in order not to bias the benefit-per-ton estimates for the rest of the Western U.S. In order to calculate the benefit-per-ton estimates, we divided the regional benefits estimates by the corresponding emissions, as shown in Table 4A-1. Lastly, we adjusted the benefit-per-ton estimates for a currency year of 2011$.[124]

This method provides estimates of the regional average benefit-per-ton for a subset of the major $PM_{2.5}$ precursors emitted from EGU sources. For precursor emissions of NO_X, there is generally a non-linear relationship between emissions and formation of $PM_{2.5}$. This means that each ton of NO_X reduced would have a different impact on ambient $PM_{2.5}$ depending on the initial level of emissions and potentially on the levels of emissions of other pollutants. In contrast, SO_2 is generally linear in forming $PM_{2.5}$. For precursors like NO_X which form $PM_{2.5}$ non-linearly, a marginal benefit-per-ton approach would better approximate the specific benefits associated with an emissions reduction scenario for a given set of base case emissions, because it would allow the benefit-per-ton to vary depending on the level of emissions reductions and the baseline emissions levels. However, we do not have sufficient air quality modeling data to calculate marginal benefit-per-ton estimates for the EGU sector. Therefore, using an average benefit-per-ton estimate for NO_X adds uncertainty to the co-benefits estimated in this RIA. Because most of the estimated co-benefits for the proposed guidelines are attributable to reductions in SO_2 emissions, the added uncertainty is likely to be small.

[124] Currently, BenMAP does not have an inflation adjustment to 2011$. We ran BenMAP for a currency year of 2010$ and calculated the benefit-per-ton estimates in 2010$. We then adjusted the resulting benefit-per-ton estimates to 2011$ using the Consumer Price Index.

Figure 4A-1. Regional Breakdown

In this RIA, we estimate emission reductions from EGUs using IPM.[125] IPM outputs provide endogenously projected unit level emissions of SO_2, NO_X, CO_2, Hg, hydrogen chloride (HCl) from EGUs, but carbon monoxide, volatile organic compounds, ammonia and total directly emitted $PM_{2.5}$ and PM_{10} emissions are post-calculated.[126] In addition, directly emitted particle emissions calculated from IPM outputs do not include speciation, i.e. they are only the total emissions. In order to conduct air quality modeling, directly emitted $PM_{2.5}$ from EGUs is speciated into components during the emissions modeling process based on emission profiles for EGUs by source classification code. Even though these speciation profiles are not unit-specific, an emission profile based on the source classification code is highly sophisticated and reflects the fuel and the unit configuration. Model-predicted concentrations of nitrate and sulfate include

[125] See Chapter 3 of this RIA for additional information regarding the Integrated Planning Model (IPM).

[126] Detailed documentation of this post-processing is available at http://www.epa.gov/airmarkets/powersectormodeling.html

both the directly emitted nitrate and sulfate from speciated $PM_{2.5}$ and secondarily formed nitrate and sulfate from emissions of NO_X and SO_2, respectively.

In order to estimate the benefits associated with reduced emissions of directly emitted particles without performing air quality modeling, we must determine the fraction of total $PM_{2.5}$ emissions comprised of elemental carbon and organic carbon (EC+OC) and crustal emissions.[127] Based on the work by Fann, Baker, and Fulcher (2012), the national average EC+OC fraction of emitted $PM_{2.5}$ is 10% with a range of 5% to 63% in different states due to the different proportion of fuels. The national average is similar to the averages for the east and west regions at 10% and 7%, respectively. Only five states had EC+OC fractions greater than 30%. For crustal emissions, the national average fraction of emitted $PM_{2.5}$ from EGUs is 78% with a range of 26% to 83%. The national average is similar to the averages for the east and west regions at 78% and 81%, respectively. Only four states had crustal fractions less than 50%. In calculating the $PM_{2.5}$ co-benefits in this RIA, we estimate the emission reductions of EC+OC and crustal emissions by applying the national average fractions (i.e., 78% crustal and 10% EC+OC) to the emission reductions of all directly emitted particles from EGUs. Because the benefit-per-ton estimates for reducing emissions of EC+OC are larger than the benefit-per-ton estimate for crustal emissions, this assumption underestimates the monetized $PM_{2.5}$ co-benefits in certain states with higher EC+OC fractions, such as California and North Dakota.

Although it is possible to calculate 95th percentile confidence intervals using the approach described in this appendix (e.g., U.S. EPA, 2011b), we generally do not calculate confidence intervals for benefit-per-ton estimates because of the additional unquantified uncertainties that result from the benefit transfer methods, including those related to the transfer of air quality modeling information. Instead, we refer the reader to Chapter 5 of PM NAAQS RIA (U.S. EPA, 2012a) for an indication of the combined random sampling error in the health impact and economic valuation functions using Monte Carlo methods. In general, the 95th percentile confidence interval for the total monetized $PM_{2.5}$ benefits ranges from approximately -90% to +180% of the central estimates based on concentration-response functions from Krewski *et al.* (2009) and Lepeule *et al.* (2012). The 95th percentile confidence interval for the health impact

[127] Crustal emissions are composed of compounds associated with minerals and metals from the earth's surface, including carbonates, silicates, iron, phosphates, copper, and zinc. Often, crustal material represents particles not classified as one of the other species (e.g., organic carbon, elemental carbon, nitrate, sulfate, chloride, etc.).

function alone ranges from approximately ±30% for mortality incidence based on Krewski *et al.* (2009) and ±46% based on Lepeule *et al.* (2012). These confidence intervals do not reflect other sources of uncertainty inherent within the estimates, such as 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 benefits estimates.

Tables 4A-3 through 4A-5 provide the regional benefit-per-ton estimates for the EGU sector at discount rates of 3% and 7% in 2020, 2025, and 2030 respectively. The benefit-per-ton values for 2020 and 2030 are based on applying the air quality modeling from 2025 to population and health information from 2020 and 2030. Estimated benefit-per-ton for these years have additional uncertainty relative to 2025 because of potential differences in atmospheric responses to reductions in $PM_{2.5}$ precursors in those years, however, these uncertainties are likely to be relatively small. Tables 4A-6 through 4A-8 provide the incidence per ton estimates (which follows the same general methodology as for the benefit-per-ton calculations) for the EGU sector in 2020, 2025, and 2030 respectively, for the set of health endpoints used to calculate the benefit-per-ton estimates.

Table 4A-3. Summary of Regional $PM_{2.5}$ Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2020 (2011$)*

Pollutant	Discount Rate	National	Region		
			East	West	California
SO_2	3%	$32,000 to $71,000	$33,000 to $75,000	$6,200 to $14,000	$95,000 to $210,000
	7%	$28,000 to $64,000	$30,000 to $68,000	$5,600 to $13,000	$85,000 to $190,000
Directly emitted $PM_{2.5}$ (EC+OC)	3%	$140,000 to $310,000	$140,000 to $320,000	$27,000 to $60,000	$370,000 to $830,000
	7%	$120,000 to $270,000	$130,000 to $290,000	$24,000 to $54,000	$330,000 to $740,000
Directly emitted $PM_{2.5}$ (Crustal)	3%	$22,000 to $49,000	$23,000 to $52,000	$11,000 to $25,000	$73,000 to $160,000
	7%	$20,000 to $44,000	$21,000 to $47,000	$9,900 to $22,000	$66,000 to $150,000
NO_X (as $PM_{2.5}$)	3%	$3,000 to $6,800	$3,100 to $7,000	$0,670 to $1,500	$22,000 to $49,000
	7%	$2,700 to $5,600	$2,800 to $6,300	$0,610 to $1,400	$19,000 to $44,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for $PM_{2.5}$. All estimates are rounded to two significant figures. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles. The estimates do not include reduced health effects from direct exposure to ozone, NO_2, SO_2, ecosystem effects, or visibility impairment.

Table 4A-4. Summary of Regional $PM_{2.5}$ Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2025 (2011$)*

Pollutant	Discount Rate	National	Region		
			East	West	California
SO_2	3%	$35,000 to $78,000	$37,000 to $83,000	$7,100 to $16,000	$110,000 to $240,000
	7%	$31,000 to $70,000	$33,000 to $75,000	$6,400 to $14,000	$97,000 to $220,000
Directly emitted $PM_{2.5}$ (EC+OC)	3%	$150,000 to $340,000	$160,000 to $360,000	$30,000 to $68,000	$410,000 to $930,000
	7%	$130,000 to $290,000	$140,000 to $320,000	$27,000 to $61,000	$370,000 to $830,000
Directly emitted $PM_{2.5}$ (Crustal)	3%	$24,000 to $55,000	$25,000 to $58,000	$12,000 to $28,000	$82,000 to $180,000
	7%	$22,000 to $49,000	$23,000 to $52,000	$11,000 to $25,000	$74,000 to $170,000
NO_X (as $PM_{2.5}$)	3%	$3,200 to $7,300	$3,300 to $7,500	$0,750 to $1,700	$24,000 to $54,000
	7%	$2,900 to $6,000	$3,000 to $6,800	$0,670 to $1,500	$22,000 to $49,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for $PM_{2.5}$. All estimates are rounded to two significant figures. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles. The estimates do not include reduced health effects from direct exposure to ozone, NO_2, SO_2, ecosystem effects, or visibility impairment.

Table 4A-5. Summary of Regional $PM_{2.5}$ Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2030 (2011$)*

Pollutant	Discount Rate	National	Region		
			East	West	California
SO_2	3%	$37,000 to $85,000	$40,000 to $89,000	$7,800 to $18,000	$120,000 to $270,000
	7%	$34,000 to $76,000	$36,000 to $81,000	$7,100 to $16,000	$110,000 to $240,000
Directly emitted $PM_{2.5}$ (EC+OC)	3%	$160,000 to $360,000	$170,000 to $380,000	$33,000 to $75,000	$450,000 to $1,000,000
	7%	$150,000 to $320,000	$150,000 to $340,000	$30,000 to $68,000	$410,000 to $920,000
Directly emitted $PM_{2.5}$ (Crustal)	3%	$26,000 to $59,000	$28,000 to $62,000	$14,000 to $31,000	$90,000 to $200,000
	7%	$24,000 to $53,000	$25,000 to $56,000	$13,000 to $28,000	$81,000 to $180,000
NO_X (as $PM_{2.5}$)	3%	$3,400 to $7,800	$3,500 to $8,000	$0,820 to $1,900	$26,000 to $60,000
	7%	$3,100 to $6,400	$3,200 to $7,200	$0,740 to $1,700	$24,000 to $54,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for $PM_{2.5}$. All estimates are rounded to two significant figures. All fine particles are assumed to have equivalent health effects, but the benefit-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The monetized benefits incorporate the conversion from precursor emissions to ambient fine particles. The estimates do not include reduced health effects from direct exposure to ozone, NO_2, SO_2, ecosystem effects, or visibility impairment.

Table 4A-6. Summary of Regional $PM_{2.5}$ Incidence-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2020*

Health Endpoint	East				West				California			
	SO_2	NO_X	EC+OC	Crustal	SO_2	NO_X	EC+OC	Crustal	SO_2	NO_X	EC+OC	Crustal
Premature Mortality												
Krewski *et al.* (2009) – adult	0.003700	0.000340	0.016000	0.002500	0.000680	0.000073	0.002900	0.001200	0.010000	0.002400	0.040000	0.008000
Lepeule *et al.* (2012) – adult	0.008300	0.000770	0.036000	0.005700	0.001500	0.000170	0.006600	0.002700	0.023000	0.005400	0.091000	0.018000
Woodruff *et al.* (1997) – infants	0.000009	0.000001	0.000037	0.000006	0.000002	0.000000	0.000007	0.000003	0.000023	0.000007	0.000097	0.000019
Morbidity												
Emergency department visits for asthma	0.001900	0.000190	0.007800	0.001300	0.000290	0.000031	0.001200	0.000470	0.005300	0.001400	0.022000	0.004200
Acute bronchitis	0.005400	0.000510	0.023000	0.003700	0.001300	0.000200	0.005200	0.002100	0.019000	0.005000	0.077000	0.015000
Lower respiratory symptoms	0.069000	0.006500	0.300000	0.047000	0.016000	0.002500	0.067000	0.026000	0.240000	0.064000	0.970000	0.190000
Upper respiratory symptoms	0.098000	0.009300	0.420000	0.068000	0.023000	0.003600	0.095000	0.038000	0.340000	0.092000	1.400000	0.270000
Minor restricted-activity days	2.700000	0.250000	11.000000	1.900000	0.580000	0.078000	2.400000	0.920000	9.400000	2.200000	35.000000	6.800000
Lost work days	0.450000	0.043000	1.900000	0.310000	0.098000	0.013000	0.410000	0.160000	1.600000	0.380000	6.000000	1.100000
Asthma exacerbation	0.240000	0.023000	1.000000	0.170000	0.056000	0.008800	0.230000	0.091000	0.840000	0.220000	3.400000	0.650000
Hospital Admissions, Respiratory	0.001100	0.000100	0.004500	0.000720	0.000150	0.000015	0.000640	0.000260	0.002500	0.000580	0.009400	0.001900
Hospital Admissions, Cardiovascular	0.001300	0.000120	0.005600	0.000910	0.000200	0.000019	0.000820	0.000330	0.003000	0.000680	0.011000	0.002200
Non-fatal Heart Attacks (age>18)												
Peters et al (2001)	0.004100	0.000390	0.018000	0.002800	0.000650	0.000064	0.002800	0.001200	0.011000	0.002400	0.041000	0.007900
Pooled estimate of 4 studies	0.000450	0.000042	0.001900	0.000310	0.000070	0.000007	0.000300	0.000130	0.001100	0.000260	0.004400	0.000850

* All estimates are rounded to two significant figures. All fine particles are assumed to have equivalent health effects, but the incidence-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The incidence benefit-per-ton estimates incorporate the conversion from precursor emissions to ambient fine particles.

Table 4A-7. Summary of Regional $PM_{2.5}$ Incidence-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2025*

Health Endpoint	East				West				California			
	SO_2	NO_X	EC+OC	Crustal	SO_2	NO_X	EC+OC	Crustal	SO_2	NO_X	EC+OC	Crustal
Premature Mortality												
Krewski *et al.* (2009) – adult	0.003900	0.000350	0.017000	0.002700	0.000750	0.000079	0.003200	0.001300	0.011000	0.002600	0.044000	0.008700
Lepeule *et al.* (2012) – adult	0.008900	0.000800	0.038000	0.006200	0.001700	0.000180	0.007300	0.003000	0.026000	0.005800	0.099000	0.020000
Woodruff *et al.* (1997) – infants	0.000008	0.000001	0.000035	0.000006	0.000002	0.000000	0.000007	0.000003	0.000022	0.000007	0.000093	0.000018
Morbidity												
Emergency department visits for asthma	0.002000	0.000200	0.006300	0.001300	0.000320	0.000033	0.001000	0.000510	0.005500	0.001500	0.018000	0.004400
Acute bronchitis	0.005700	0.000520	0.024000	0.003900	0.001300	0.000210	0.005600	0.002200	0.020000	0.005300	0.080000	0.015000
Lower respiratory symptoms	0.072000	0.006700	0.310000	0.050000	0.017000	0.002700	0.071000	0.028000	0.250000	0.067000	1.000000	0.200000
Upper respiratory symptoms	0.100000	0.009600	0.440000	0.071000	0.024000	0.003800	0.100000	0.040000	0.360000	0.096000	1.500000	0.280000
Minor restricted-activity days	2.800000	0.250000	12.000000	1.900000	0.610000	0.083000	2.500000	0.970000	9.600000	2.300000	36.000000	6.900000
Lost work days	0.470000	0.043000	2.000000	0.320000	0.100000	0.014000	0.430000	0.160000	1.600000	0.390000	6.100000	1.200000
Asthma exacerbation	0.250000	0.023000	1.100000	0.170000	0.059000	0.009300	0.250000	0.097000	0.880000	0.230000	3.500000	0.680000
Hospital Admissions, Respiratory	0.001200	0.000110	0.005100	0.000810	0.000180	0.000017	0.000740	0.000300	0.002800	0.000650	0.011000	0.002100
Hospital Admissions, Cardiovascular	0.001400	0.000130	0.006200	0.001000	0.000220	0.000022	0.000930	0.000380	0.003300	0.000750	0.012000	0.002400
Non-fatal Heart Attacks (age>18)												
Peters et al (2001)	0.004600	0.000430	0.020000	0.003100	0.000740	0.000071	0.003200	0.001300	0.012000	0.002700	0.046000	0.008900
Pooled estimate of 4 studies	0.000490	0.000046	0.002100	0.000340	0.000080	0.000008	0.000340	0.000140	0.001300	0.000290	0.004900	0.000950

* All estimates are rounded to two significant figures. All fine particles are assumed to have equivalent health effects, but the incidence-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The incidence benefit-per-ton estimates incorporate the conversion from precursor emissions to ambient fine particles.

Table 4A-8. Summary of Regional $PM_{2.5}$ Incidence-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2030*

Health Endpoint	East				West				California			
	SO_2	NO_X	EC+OC	Crustal	SO_2	NO_X	EC+OC	Crustal	SO_2	NO_X	EC+OC	Crustal
Premature Mortality												
Krewski *et al.* (2009) – adult	0.004200	0.000380	0.018000	0.002900	0.000840	0.000087	0.003600	0.001500	0.013000	0.002800	0.048000	0.009600
Lepeule *et al.* (2012) – adult	0.009600	0.000850	0.041000	0.006700	0.001900	0.000200	0.008100	0.003400	0.029000	0.006400	0.110000	0.022000
Woodruff *et al.* (1997) – infants	0.000008	0.000001	0.000033	0.000005	0.000002	0.000000	0.000007	0.000003	0.000021	0.000006	0.000088	0.000017
Morbidity												
Emergency department visits for asthma	0.001600	0.000160	0.006600	0.001100	0.000260	0.000027	0.001100	0.000420	0.004500	0.001200	0.019000	0.003500
Acute bronchitis	0.005900	0.000540	0.025000	0.004100	0.001400	0.000220	0.005900	0.002300	0.021000	0.005400	0.083000	0.016000
Lower respiratory symptoms	0.075000	0.006800	0.320000	0.052000	0.018000	0.002800	0.075000	0.030000	0.260000	0.069000	1.100000	0.200000
Upper respiratory symptoms	0.110000	0.009800	0.460000	0.074000	0.026000	0.004000	0.110000	0.042000	0.370000	0.099000	1.500000	0.290000
Minor restricted-activity days	2.900000	0.260000	12.000000	2.000000	0.650000	0.088000	2.700000	1.000000	9.800000	2.300000	37.000000	7.100000
Lost work days	0.480000	0.043000	2.000000	0.330000	0.110000	0.015000	0.450000	0.170000	1.700000	0.400000	6.300000	1.200000
Asthma exacerbation	0.260000	0.024000	1.100000	0.180000	0.063000	0.009800	0.260000	0.100000	0.920000	0.240000	3.700000	0.710000
Hospital Admissions, Respiratory	0.001300	0.000120	0.005600	0.000900	0.000200	0.000019	0.000830	0.000340	0.003200	0.000740	0.012000	0.002400
Hospital Admissions, Cardiovascular	0.001600	0.000150	0.006800	0.001100	0.000250	0.000024	0.001000	0.000420	0.003800	0.000850	0.014000	0.002700
Non-fatal Heart Attacks (age>18)												
Peters et al (2001)	0.005000	0.000460	0.021000	0.003500	0.000830	0.000079	0.003600	0.001500	0.014000	0.003100	0.052000	0.010000
Pooled estimate of 4 studies	0.000540	0.000049	0.002300	0.000370	0.000090	0.000009	0.000380	0.000160	0.001500	0.000330	0.005600	0.001100

* All estimates are rounded to two significant figures. All fine particles are assumed to have equivalent health effects, but the incidence-per-ton estimates vary depending on the location and magnitude of their impact on $PM_{2.5}$ levels, which drive population exposure. The incidence benefit-per-ton estimates incorporate the conversion from precursor emissions to ambient fine particles.

4A.4 Regional Ozone Benefit-per-Ton Estimates

The process for generating the regional ozone benefit-per-ton estimates is consistent with the process for $PM_{2.5.}$ Ozone is not directly emitted, and is a non-linear function of NO_X and VOC emissions. For the purpose of estimating benefit-per-ton for this RIA, we assume that all of the ozone impacts from EGUs are attributable to NO_X emissions. VOC emissions, which are also a precursor to ambient ozone formation, are insignificant from the EGU sector relative to both NO_X emissions from EGUs and the total VOC emissions inventory. Therefore, we believe that our assumption that EGU-attributable ozone formation at the regional-level is due to NO_X alone is reasonable.

Similar to $PM_{2.5}$, this method provides estimates of the regional average benefit-per-ton. Due to the non-linear chemistry between NO_X emissions and ambient ozone, using an average benefit-per-ton estimate for NO_X adds uncertainty to the ozone co-benefits estimated for the proposed guidelines. Because most of the estimated co-benefits for the proposed guidelines are attributable to changes in ambient $PM_{2.5}$, the added uncertainty is likely to be small.

In the ozone co-benefits estimated in this RIA, we apply the benefit-per-ton estimates calculated using NO_X emissions derived from modeling the Clean Power Plan proposal during the ozone-season only (May to September). As shown in Table 4A-1, ozone-season NO_X emissions from EGUs are slightly less than half of all-year NO_X emissions. Because we estimate ozone health impacts from May to September only, this approach underestimates ozone co-benefits in areas with longer ozone seasons such as southern California and Texas. When the underestimated benefit-per-ton estimate is multiplied by ozone-season only NO_X emission reductions, this results in an underestimate of the monetized ozone co-benefits. For illustrative purposes, Tables 4A-9 through 4A-11 provide the ozone benefit-per-ton estimates using both all-year NO_X emissions and ozone-season only NO_X for 2020, 2025, and 2030, respectively. Tables 4A-12 through 4A-14 provide the ozone season incidence-per-ton estimates for 2020, 2025, and 2030, respectively. Similar to $PM_{2.5}$, the ozone benefit-per-ton values for 2020 and 2030 are based on applying the air quality modeling from 2025 to population and health information from 2020 and 2030. Estimated benefit-per-ton for these years have additional uncertainty relative to 2025 because of potential differences in atmospheric responses to reductions in ozone precursors in those years. Uncertainties may be somewhat larger in the case of ozone due to high degree of dependence of ozone responses to baseline meteorology and emissions levels.

Table 4A-9. Summary of Regional Ozone Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2020 (2011$)*

Ozone precursor Pollutant	National	Regional		
		East	West	California
Ozone season NO_X	$6,000 to $26,000	$6,500 to $28,000	$2,000 to $8,900	$14,000 to $59,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for ozone. All estimates are rounded to two significant figures. The monetized benefits incorporate the conversion from NO_X precursor emissions to ambient ozone.

Table 4A-10. Summary of Regional Ozone Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2025 (2011$)*

Ozone precursor Pollutant	National	Regional		
		East	West	California
Ozone season NO_X	$6,600 to $27,000	$7,100 to $30,000	$2,300 to $10,000	$15,000 to $66,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for ozone. All estimates are rounded to two significant figures. The monetized benefits incorporate the conversion from NO_X precursor emissions to ambient ozone.

Table 4A-11. Summary of Regional Ozone Benefit-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2030 (2011$)*

Ozone precursor Pollutant	National	Regional		
		East	West	California
Ozone season NO_X	$7,100 to $29,000	$7,600 to $33,000	$2,600 to $11,000	$17,000 to $73,000

* The range of estimates reflects the range of epidemiology studies for avoided premature mortality for ozone. All estimates are rounded to two significant figures. The monetized benefits incorporate the conversion from NO_X precursor emissions to ambient ozone.

Table 4A-12. Summary of Regional Ozone Incidence-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2020*

Health Endpoint	East	West	California
Premature Mortality – adult			
Bell *et al.* (2004)	0.000600	0.000190	0.001300
Levy *et al.* (2005)	0.002800	0.000880	0.005800
Morbidity			
Hospital Admissions, Respiratory (ages > 65)	0.003500	0.000900	0.006600
Hospital Admissions, Respiratory (ages < 2)	0.001800	0.000780	0.003300
Emergency Room Visits, Respiratory	0.002000	0.000500	0.003900
Acute Respiratory Symptoms	3.500000	1.300000	8.800000
School Loss Days	1.200000	0.490000	3.000000

* All estimates are rounded to two significant figures. The incidence benefit-per-ton estimates incorporate the conversion from NO_X precursor emissions to ambient ozone. These estimates reflect ozone-season NO_X emissions.

Table 4A-13. Summary of Regional Ozone Incidence-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2025*

Health Endpoint	East	West	California
Premature Mortality – adult			
Bell *et al.* (2004)	0.000640	0.000210	0.001400
Levy *et al.* (2005)	0.002900	0.000970	0.006400
Morbidity			
Hospital Admissions, Respiratory (ages > 65)	0.004100	0.001100	0.007800
Hospital Admissions, Respiratory (ages < 2)	0.001800	0.000820	0.003400
Emergency Room Visits, Respiratory	0.002000	0.000540	0.004100
Acute Respiratory Symptoms	3.600000	1.400000	8.900000
School Loss Days	1.300000	0.520000	3.200000

* All estimates are rounded to two significant figures. The incidence benefit-per-ton estimates incorporate the conversion from NO_X precursor emissions to ambient ozone. These estimates reflect ozone-season NO_X emissions.

Table 4A-14. Summary of Regional Ozone Incidence-per-Ton Estimates Based on Air Quality Modeling from Proposed Clean Power Plan in 2030*

Health Endpoint	East	West	California
Premature Mortality – adult			
Bell *et al.* (2004)	0.000640	0.000230	0.001800
Levy *et al.* (2005)	0.002900	0.001100	0.008200
Morbidity			
Hospital Admissions, Respiratory (ages > 65)	0.004400	0.001300	0.011000
Hospital Admissions, Respiratory (ages < 2)	0.001800	0.000860	0.004100
Emergency Room Visits, Respiratory	0.002000	0.000580	0.005000
Acute Respiratory Symptoms	3.500000	1.500000	11.000000
School Loss Days	1.200000	0.550000	3.800000

* All estimates are rounded to two significant figures. The incidence benefit-per-ton estimates incorporate the conversion from NO_X precursor emissions to ambient ozone. These estimates reflect ozone-season NO_X emissions.