Regulatory Impact Analysis for the Final National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units Review of the Residual Risk and Technology Review

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
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ES.1 Introduction

Exposure to hazardous air pollutants ("HAP," sometimes known as toxic air pollution, including mercury (Hg), chromium, arsenic, and lead) can cause a range of adverse health effects including harming people's central nervous system; damage to their kidneys; and cancer. These adverse effects can be particularly acute for communities living near sources of HAP. Recognizing the dangers posed by HAP, Congress enacted Clean Air Act (CAA) section 112. Under CAA section 112, EPA is required to set standards based on maximum achievable control technology (known as "MACT" standards) for major sources[1] of HAP that "require the maximum degree of reduction in emissions of the hazardous air pollutants . . . (including a prohibition on such emissions, where achievable) that the Administrator, taking into consideration the cost of achieving such emission reduction, and any nonair quality health and environmental impacts and energy requirements, determines is achievable." 42 U.S.C. 7412(d)(2). EPA is further required to "review, and revise" those standards every eight years "as necessary (taking into account developments in practices, processes, and control technologies)." *Id.* 7412(d)(6).

On January 20, 2021, President Biden signed Executive Order (E.O.) 13990, "Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis" (86 FR 7037; January 25, 2021). The executive order, among other things, instructed EPA to review the 2020 final rule titled *National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units—Reconsideration of Supplemental Finding and Residual Risk and Technology Review* (85 FR 31286; May 22, 2020) (2020 Final Action) and to consider publishing a notice of proposed rulemaking suspending, revising, or rescinding that action. The 2020 Final Action included two parts: (1) a finding that it is not appropriate and necessary to regulate coal- and oil-fired electric utility steam generating units (EGUs) under CAA section 112; and (2) the risk and technology review (RTR) for the 2012 Mercury and Air Toxics (MATS) Final Rule.

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[1] The term "major source" means any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has the potential to emit considering controls, in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants. 42 U.S.C. 7412(a)(1).

EPA reviewed both parts of the 2020 Final Action. The results of EPA's review of the first part, finding it is appropriate and necessary to regulate EGUs under CAA section 112, was proposed on February 9, 2022 (87 FR 7624) (2022 Proposal) and finalized on March 6, 2023 (88 FR 13956). In the 2022 Proposal, EPA also solicited information on the performance and cost of new or improved technologies that control HAP emissions, improved methods of operation, and risk-related information to further inform EPA's review of the second part, the 2020 MATS RTR. EPA proposed amendments to the RTR on April 24, 2023 (88 FR 24854) (2023 Proposal) and this action finalizes those amendments and presents the final results of EPA's review of the MATS RTR. This RIA presents the expected economic consequences of EPA's final MATS RTRRTR. As EPA determined not to reopen the 2020 Residual Risk Review, and accordingly did not propose or finalize any revisions to that review, no projected impacts are associated with the residual risk review.

This RIA is prepared in accordance with E.O. 12866 and 14904, the guidelines of OMB Circular A-4, and EPA's *Guidelines for Preparing Economic Analyses* (2014).T. The RIA analyzes the benefits and costs associated with the projected emissions reductions under the final requirements to inform EPA and the public about these projected impacts. The projected benefits and costs of the final rule and less stringent regulatory alternative are presented for the period from 2028 to 2037.[2]

ES.2 Regulatory Requirements

For coal-fired EGUs, the 2012 MATS rule established standards to limit emissions of Hg, acid gas HAP, non-Hg HAP metals (e.g., nickel, lead, chromium), and organic HAP (e.g., formaldehyde, dioxin/furan). For oil-fired EGUs, the 2012 MATS rule established standards to limit emissions of hydrogen chloride (HCl) and hydrogen fluoride (HF), total HAP metals (e.g., Hg, nickel, lead), and organic HAP (e.g., formaldehyde, dioxin/furan).

This RIA focuses on evaluating the benefits, costs, and other impacts of four amendments to the 2012 MATS rule:

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[2] Circular A-4 was recently revised. The effective date of the revised Circular A-4 (2023) is March 1, 2024, for regulatory analyses received by OMB in support of proposed rules, interim final rules, and direct final rules, and January 1, 2025, for regulatory analyses received by OMB in support of other final rules. For all other rules, Circular A-4 (2003) is applicable until those dates.

- **Lowering the Standard for Non-Hg HAP Metals Emissions for Existing Coal-fired EGUs:** Existing coal-fired EGUs are subject to numeric emission limits for fPM, a surrogate for the total non-Hg HAP metals. MATS currently requires existing coal-fired EGUs to meet a fPM emission standard of 0.030 pounds per million British thermal units (lb/MMBtu) of heat input. After reviewing updated information on the current emission levels of fPM from existing coal-fired EGUs and the costs of meeting a standard more stringent than 0.030 lb/MMBtu, EPA is finalizing a fPM emission standard for existing coal-fired EGUs of 0.010 lb/MMBtu. Additionally, EPA is finalizing updated limits for non-Hg HAP metals and total non-Hg HAP metals that have been reduced proportional to the reduction of the fPM emission limit. EGU owners or operators who would choose to comply with the non-Hg HAP metals emission limits instead of the surrogate fPM limit must request and receive approval to use a non-Hg HAP metal continuous monitoring system as an alternative test method (e.g., multi-metal continuous monitoring system) under the provisions of 40 CFR 63.7(f).
- **Hg Emission Standard for Lignite-fired EGUs:** EPA is also finalizing a revision to the Hg emission standard for existing lignite-fired EGUs. Until this final rule, lignite-fired EGUs must meet a Hg emission standard of 4.0 pounds per trillion British thermal units (lb/TBtu) or 4.0E-2 pounds per gigawatt hour (lb/GWh). EPA is finalizing the requirement that lignite-fired EGUs meet the same standard as existing EGUs firing other types of coal, which is 1.2 lb/TBtu or 1.3E-2 lb/GWh.
- **Continuous Emissions Monitoring Systems:** After considering updated information on the costs for performance testing compared to the cost of PM CEMS and capabilities of PM CEMS measurement abilities, as well as the benefits of using PM CEMS, which include increased transparency, compliance assurance, and accelerated identification of anomalous emissions, EPA is finalizing the requirement that coal- and oil-fired units demonstrate compliance with the fPM emission standard by using PM CEMS. Prior to this final rule, EGUs had a choice of demonstrating compliance with the non-Hg HAP metals by monitoring fPM with quarterly sampling or using PM CEMS. EPA proposed to require PM CEMS for existing integrated gasification combined cycle (IGCC) EGUs but is not finalizing this requirement due to technical issues calibrating CEMS on these types of EGUs and the related fact that fPM emissions from IGCCs are very low.
- **Startup Definitions:** Separate from the technology review, EPA is finalizing the removal of one of the two options for defining the startup period for EGUs. The first option defines startup as either the first-ever firing of fuel in a boiler for the purpose of producing electricity, or the firing of fuel in a boiler after a shutdown event for any purpose. In the second option, startup is defined as the period in which operation of an EGU is initiated for any purpose. EPA is removing the second option, which is currently being used by fewer than 10 EGUs.

More detail regarding these amendments can be found in the preamble of the final rule and in Section 1.3.1 of this document.

Table ES-1 summarizes how we have structured the regulatory options to be analyzed in this RIA. The finalized regulatory option includes the amendments just discussed in this section: the revision to the fPM standard to 0.010 lb/MMBtu, in which PM is a surrogate for non-Hg HAP metals, the revision to the Hg standard for lignite-fired EGUs to 1.2 lb/TBtu, the requirement to use PM CEMS to demonstrate compliance, and the removal of the startup definition number two. The less stringent regulatory option examined in this RIA assumed the fPM and Hg limits remain unchanged and examines just the finalized PM CEMS requirement and removal of startup definition number two.

Table ES-1 Summary of Regulatory Options Examined in this RIA

	Regulatory Options Examined in this RIA	
Provision	**Finalized**	**Less Stringent**
FPM Standard (Surrogate Standard for Non-Hg HAP metals)	Revised fPM standard of 0.010 lb/MMBtu	Retain existing fPM standard of 0.030 lb/MMBtu
Hg Standard	Revised Hg standard for lignite-fired EGUs of 1.2 lb/TBtu	Retain Hg standard for lignite-fired EGUs of 4.0 lb/TBtu
Continuous Emissions Monitoring Systems (PM CEMS)	Require installation of PM CEMS to demonstrate compliance	Require installation of PM CEMS to demonstrate compliance
Startup Definition	Remove startup definition #2	Remove startup definition #2

The compliance date for affected coal-fired sources to comply with the revised fPM limit of 0.010 lb/MMBtu and for lignite-fired sources to meet with the lower Hg limit of 1.2 lb/Tbtu is three years after the effective date of the final rule. EPA is finalizing the requirement that affected sources use PM CEMS for compliance demonstration by three years after the effective date of the final rule. The compliance date for existing affected sources to comply with amendments pertaining to the startup definition is 180 days after the effective date of the final rule.

Both the finalized and less stringent options described in Table ES-1 have not been changed from the final rule and less stringent options examined in the RIA for the proposal of this action. The proposal RIA included a more stringent regulatory option that projected the impacts of a lowering the fPM standard to 0.006 lb/MMBtu, while holding the other three proposed amendments unchanged from the proposed option. EPA solicited comment on this more stringent fPM standard in the preamble of the proposed rule. As explained in the preamble of the final rule, EPA determined not to pursue a more stringent standard for fPM emissions, such as a limit of 0.006 lb/MMBtu. After considering comments to the proposed rule and conducting additional analysis, EPA determined that a fPM standard lower than 0.010 lb/MMBtu would not currently be compatible with PM CEMS due to measurement uncertainty. While a fPM emission limit of 0.006 lb/MMBtu paired with the use of quarterly stack testing may appear to be more stringent than the 0.010 lb/MMBtu standard paired with the use of PM CEMS that the EPA is finalizing in this rule, there is no way to confirm emission reductions during periods in between quarterly stack tests when emission rates may be higher. Therefore, the Agency is finalizing a fPM limit of 0.010 lb/MMBtu with the use of PM CEMS as the only means of compliance demonstration. EPA has determined that this combination of fPM limit and compliance demonstration represents the most stringent option taking into account the statutory considerations.

ES.3 Baseline and Analysis Years

The impacts of regulatory actions are evaluated relative to a modeled baseline that represents expected behavior in the electricity sector under market and regulatory conditions in the absence of a regulatory action. EPA frequently updates the power sector modeling baseline to reflect the latest available electricity demand forecasts from the U.S. Energy Information Administration (EIA) as well as expected costs and availability of new and existing generating resources, fuels, emission control technologies, and regulatory requirements.

The baseline for this final rule includes the Good Neighbor Plan (GNP), the Revised Cross-State Air Pollution Rule (CSAPR) Update, CSAPR Update, and CSAPR, MATS, the 2015 Effluent Limitation Guidelines (ELG) and the 2015 Coal Combustion Residuals (CCR), and the recently finalized 2020 ELG and CCR rules.[3] This version of the model also includes recent updates to state and federal legislation affecting the power sector, including Public Law 117-169, 136 Stat. 1818 (August 16, 2022), commonly known as the Inflation Reduction Act of 2022 (the IRA). The modeling documentation includes a summary of all legislation reflected in this version

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[3] For a full list of modeled policy parameters, please see: *https://www.epa.gov/power-sector-modeling*.

of the model as well as a description of how that legislation is implemented in the model.[4] Also, see Section 3.3 for additional detail about the power sector baseline for this RIA.

The year 2028 is the first year of detailed power sector modeling for this RIA and approximates when the impacts of the final rule on the power sector will begin.[5,6] In addition, the regulatory impacts are evaluated for the specific analysis years of 2030 and 2035. These results are used to estimate the present value (PV) and equivalent annualized value (EAV) of the 2028 through 2037 period, discounted to 2023.

ES.4 Emissions Impacts

EPA estimated emission reductions under the final rule for the years 2028, 2030, and 2035 based upon IPM projections. The quantified emissions estimates were developed with the EPA's Power Sector Modeling Platform 2023 using IPM, a state-of-the-art, peer-reviewed dynamic, deterministic linear programming model of the contiguous U.S. electric power sector. IPM provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies while meeting electricity demand and various environmental, transmission, dispatch, and reliability constraints. IPM's least-cost dispatch solution is designed to ensure generation resource adequacy, either by using existing resources or through the construction of new resources. IPM addresses reliable delivery of generation resources for the delivery of electricity between the 78 IPM regions, based on current and planned transmission capacity, by setting limits to the ability to transfer power between regions using the bulk power transmission system. The model includes state-of-the-art estimates of the cost and performance of air pollution control technologies with respect to Hg and other HAP controls.

The quantified emission estimates presented in the RIA include changes in pollutants directly covered by this rule, such as Hg and non-Hg HAP metals, and changes in other pollutants emitted from the power sector as a result of the compliance actions projected under

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[4] Documentation for EPA's Power Sector Modeling Platform 2023 using IPM can be found at *https://www.epa.gov/power-sector-modeling* and is available in the docket for this action.

[5] Note that the Agency has granted the maximum time allowed for compliance under CAA section 112(i)(3) of three years, and individual facilities may seek, if warranted, an additional 1-year extension of the compliance from their permitting authority pursuant to CAA section 112(i)(3)(B). Facilities may also request, if warranted, emergency authority to operate through the Department of Energy under section 202(c) of the Federal Power Act.

[6] We note that, while the compliance date of the rule will likely be mid- to late-2027 and all compliance costs are accounted for, any emissions reductions and benefits that in occur over a few months in 2027 are omitted from this analysis.

this final rule. The model projections capture the emissions changes associated with implementation of HAP mitigation measures at affected sources as well as the resulting effects on dispatch as the relative operating costs for some affected units have changed. Table ES-2 presents the estimated impact on power sector emissions resulting from compliance with the final rule in the contiguous U.S. As the incremental cost of operating PM CEMS relative to baseline requirements is small relative to the ongoing costs of operation, it is not necessary to model the less stringent regulatory alternative using IPM. The estimation of impacts outside of the model is a reasonable approach given the relatively small costs.

Table ES-2 Projected EGU Emissions and Emissions Changes for the Baseline and under the Final Rule for 2028, 2030, and 2035[a]

		Total Emissions			
	Year	Baseline	Final Rule	Change from Baseline	% Change under Final Rule
Hg (lbs.)	2028	6,129	5,129	-999.1	-16.3%
	2030	5,863	4,850	-1,013	-17.3%
	2035	4,962	4,055	-907.0	-18.3%
PM$_{2.5}$ (thousand tons)	2028	70.5	69.7	-0.77	-1.09%
	2030	66.3	65.8	-0.53	-0.79%
	2035	50.7	50.2	-0.47	-0.93%
PM$_{10}$ (thousand tons)	2028	79.5	77.4	-2.07	-2.60%
	2030	74.5	73.1	-1.33	-1.79%
	2035	56.0	54.8	-1.18	-2.11%
SO$_2$ (thousand tons)	2028	454.3	454.0	-0.290	-0.06%
	2030	333.5	333.5	0.025	0.01%
	2035	239.9	239.9	-0.040	-0.02%
Ozone-season NO$_X$ (thousand tons)	2028	189.0	188.8	-0.165	-0.09%
	2030	174.99	175.4	0.488	0.28%
	2035	116.99	119.1	2.282282	1.95%
Annual NO$_X$ (thousand tons)	2028	460.55	460.3	-0.283	-0.06%
	2030	392.88	392.7	-0.022	-0.01%
	2035	253.44	253.5	0.066	0.03%
HCl (thousand tons)	2028	2.474	2.474	0.000	0.01%
	2030	2.184	2.184	0.000	0.01%
	2035	1.484	1.485	0.001	0.06%
CO$_2$ (million metric tons)	2028	1,158.8	1,158.7	-0.0655	-0.01%
	2030	1,098.3	1,098.3	0.0361	0.00%
	2035	724.2	724.1	-0.099	-0.01%

[a] This analysis is limited to the geographically contiguous lower 48 states. Values are independently rounded and may not sum.

We also estimate that the final rule will reduce at least seven tons of non-Hg HAP metals in 2028, five tons of non-Hg HAP metals in 2030, and four tons of non-Hg HAP metals in 2035.[7]

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[7] The estimates on non-mercury HAP metals reductions were obtained by multiplying the ratio of non-mercury HAP metals to fPM by estimates of PM$_{10}$ reductions under the rule, as we do not have estimates of fPM reductions using IPM, only PM$_{10}$. The ratios of non-mercury HAP metals to fPM were based on analysis of 2010 MATS Information Collection Request (ICR) data. As there may be substantially more fPM than PM$_{10}$ reduced by the control techniques projected to be used under this rule, these estimates of non-mercury HAP metals reductions are likely underestimates. More detail on the estimated reduction in non-mercury HAP metals can be found in the docketed memorandum *Estimating Non-Hg HAP Metals Reductions for the 2024 Technology Review for the Coal-Fired EGU Source Category.*

These reductions are composed of reductions in emissions of antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, nickel, and selenium.

Importantly, the continuous monitoring of fPM required in this rule will likely induce additional emissions reductions that we are unable to quantify. Continuous measurements of emissions accounts for unforeseeable changes to processes and fuels, fluctuations in load, operations of pollution controls, and equipment malfunctions. By measuring emissions across all operations, power plant operators and regulators can use the data to ensure controls are operating properly and to assess compliance with relevant standards. Because CEMS enable power plant operators to quickly identify and correct problems with pollution control devices, it is possible that fPM emissions could be lower than they otherwise would have been for up to three months—or up to three years if testing less frequently under the LEE program— at a time. This potential reduction in fPM and non-Hg HAP metals emission resulting from the information provided by continuous monitoring coupled with corrective actions by plant operators could be sizeable over the existing coal-fired fleet and is not quantified in this rulemaking. Further discussion of the emissions transparency provided by PM CEMS is available in the "2024 Update to the 2023 Proposed Technology Review for the Coal- and Oil-Fired EGU Source Category" memorandum, available in the docket.

As we are finalizing the removal of paragraph (2) of the definition of "startup," the time period for engaging fPM or non-Hg HAP metal controls after non-clean fuel use, as well as for full operation of fPM or non-Hg HAP metal controls, is expected to be reduced when transitioning to paragraph (1). The reduced time period for engaging controls therefore increases the duration in which pollution controls are employed and lowers emissions.

To the extent that the CEMS requirement and removal of the second definition of startup leads to actions that may otherwise not occur absent the amendments to those provisions in this final rule, there may be emissions impacts we are unable to estimate.

ES.5 Compliance Costs

The power industry's compliance costs are represented in this analysis as the change in electric power generation costs between the baseline and policy scenarios. In other words, these costs are an estimate of the increased power industry expenditures required to implement the final requirements of this rule. The compliance cost estimates were mainly developed using the EPA's Power Sector Modeling Platform 2023 using IPM. The incremental costs of the final rule's PM CEMS requirement were estimated outside of IPM and added to the IPM-based cost estimate presented here and in Section 3 of the RIA.

The baseline includes approximately 5 GW of operational EGU capacity designed to burn low rank virgin coal (i.e., lignite) in 2028. All of this capacity is currently equipped with Activated Carbon Injection (ACI) technology, which is designed to reduce Hg emissions, and operation of this technology for compliance with existing Hg emissions limits (e.g., MATS and other enforceable state regulations) is reflected in the baseline. In the final rule modeling scenario, each of these EGUs projected to consume lignite is assigned an additional variable operating cost that is consistent with improvements in sorbent that EPA assumes are necessary to achieve the finalized lower limit. In the final rule, this additional cost does not result in incremental retirements for these units, nor does it result in a significant change to the projected generation level for these units.

In 2028, the baseline projection also includes 11.6 GW of operational coal capacity that, based on the analysis documented in the EPA memorandum titled "2024 Update to the 2023 Proposed Technology Review for the Coal- and Oil-Fired EGU Source Category," EPA assumes would either need to improve existing PM controls or install new PM controls to comply with the final rule. With the exception of one facility (Colstrip, located in Montana), all of that 11.6 GW is currently operating existing electrostatic precipitators (ESPs) and/or fabric filters, and all of that capacity is projected to install control upgrades and remain operational in 2028 in the IPM policy scenario.

Table ES-3 below summarizes the PV and EAV of the total national compliance cost estimates for EGUs for the final rule and the less stringent alternative. We present the PV of the costs over the 10-year period of 2028 to 2037. We also present the EAV, which represents a flow of constant annual values that, had they occurred annually, would yield a sum equivalent to the PV. The EAV represents the value of a typical cost for each year of the analysis.

We note that IPM provides EPA's best estimate of the costs of the rules to the electricity sector. These compliance cost estimates are used as a proxy for the social cost of the rule.

Chapter 3 reports how annual power costs are projected to change over the time period of analysis.[8]

Table ES-3 Total Compliance Cost Estimates for the Final Rule and the Less Stringent Alternative (millions of 2019 dollars, discounted to 2023)

	2% Discount Rate		3% Discount Rate		7% Discount Rate	
Regulatory Option	**PV**	**EAV**	**PV**	**EAV**	**PV**	**EAV**
Final Rule	860	96	790	92	560	80
Less Stringent	19	2.3	18	2.1	13	1.8

Note: Values have been rounded to two significant figures.

Additionally, to the extent that the CEMS requirement and removal of the second definition of startup lead to actions that may otherwise not occur absent the amendments to those provisions in this final rule, there may be cost impacts we are unable to estimate. With respect to the finalized removal of the startup definition, as the majority of EGUs currently rely on work practice standards under paragraph (1) of the definition of "startup," we believe this change is achievable by all EGUs and would result in little to no additional expenditures, especially since the additional reporting and recordkeeping requirements associated with use of paragraph (2) would no longer apply.

The compliance costs for the final rule are higher than the estimates in the RIA for the proposal of this action, largely due to changes in fPM control assumptions. At proposal, EPA estimated that incremental fPM controls would be required for about 5 GW of operational coal capacity. Based on public comments, the Agency reevaluated the unit-level data and now estimates that nearly three times more capacity would require incremental fPM controls (14 GW of operational coal capacity). It is also important to note that EPA also updated the IPM baseline power sector modeling.

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[8] Results using the 2 percent discount rate were not included in the proposal for this action. The 2003 version of OMB's Circular A-4 had generally recommended 3 percent and 7 percent as default rates to discount social costs and benefits. The analysis of the proposed rule used these two recommended rates. In November 2023, OMB finalized an update to Circular A-4, in which it recommended the general application of a 2 percent rate to discount social costs and benefits (subject to regular updates), which is an estimate of consumption-based discount rate. Given the substantial evidence supporting a 2 percent discount rate, we include cost and benefits results calculated using a 2 percent discount rate consistent with the update to Circular A-4.

ES.6 Benefits

ES.6.1 Health Benefits

ES.6.1.1 Hazardous Air Pollutants

This final rule is projected to reduce emissions of Hg and non-Hg HAP metals. Hg emitted from U.S. EGUs can deposit to watersheds and associated waterbodies where it can accumulate as Methylmercury (MeHg) in fish. MeHg is formed by microbial action in the top layers of sediment and soils, after Hg has precipitated from the air and deposited into waterbodies or land. Once formed, MeHg is taken up by aquatic organisms and bioaccumulates up the aquatic food web. MeHg in fish, originating from U.S. EGUs, is consumed both as self-caught fish by subsistence fishers and as commercial fish by the general population. Exposure to MeHg is known to have adverse impacts on neurodevelopment and the cardiovascular system. MeHg is known to exert some genotoxic activity and EPA has classified MeHg as a “possible” human carcinogen. The projected reductions in Hg are expected to reduce the bioconcentration of MeHg in fish. As part of the 2020 risk review, EPA examined risk to subsistence fishers from MeHg exposure at a lake near three U.S. EGU lignite-fired facilities (U.S. EPA, 2020). While the analysis that EPA completed suggests that exposures associated with Hg emitted from EGUs, including lignite-fired EGUs, are below levels of concern from a public health standpoint, further reductions in these emissions should further decrease fish burden and exposure through fish consumption including exposures to subsistence fishers to MeHg.

In addition, U.S. EGUs are a major source of HAP metals emissions including arsenic, beryllium, cadmium, chromium, cobalt, lead, nickel, manganese, and selenium. Some HAP metals emitted by U.S. EGUs are known to be persistent and bioaccumulative and others have the potential to cause cancer. Exposure to these HAP metals, depending on exposure duration and levels of exposures, is associated with a variety of adverse health effects. These adverse health effects may include chronic health disorders (e.g., irritation of the lung, skin, and mucus membranes; decreased pulmonary function, pneumonia, or lung damage; detrimental effects on the central nervous system; damage to the kidneys; and alimentary effects such as nausea and vomiting. The emissions reductions projected under this final rule from the use of PM controls are expected to reduce exposure of individuals residing near these facilities to non-Hg HAP metals, including carcinogenic HAP.

ES.6.1.1 Criteria Pollutants

This rule is expected to reduce emissions of directly emitted $PM_{2.5}$, NO_X and SO_2 throughout the year. Because NO_X and SO_2 are also precursors to secondary formation of ambient $PM_{2.5}$, reducing these emissions would reduce human exposure to ambient $PM_{2.5}$ throughout the year and would reduce the incidence of $PM_{2.5}$-attributable health effects.

This final rule is expected to reduce ozone season NO_X emissions. In the presence of sunlight, NO_X, and volatile organic compounds (VOCs) can undergo a chemical reaction in the atmosphere to form ozone. Reducing NO_X emissions generally reduces human exposure to ozone and the incidence of ozone-related health effects, though the degree to which ozone is reduced will depend in part on local concentration levels of VOCs.

In this RIA, EPA reports estimates of the health benefits of changes in $PM_{2.5}$ and ozone concentrations. The health effect endpoints, effect estimates, benefit unit-values, and how they were selected, are described in the Technical Support Document (TSD) titled *Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits* (U.S. EPA, 2023). This document, hereafter referred to as the "Health Benefits TSD," can be found in the docket for this rulemaking. Our approach for updating the endpoints and to identify suitable epidemiologic studies, baseline incidence rates, population demographics, and valuation estimates is summarized in Section 4.3.

ES.6.2 Climate Benefits

Elevated concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere have been warming the planet, leading to changes in the Earth's climate including changes in the frequency and intensity of heat waves, precipitation, and extreme weather events, rising seas, and retreating snow and ice. The well-documented atmospheric changes due to anthropogenic GHG emissions are changing the climate at a pace and in a way that threatens human health, society, and the natural environment. Climate change touches nearly every aspect of public welfare in the U.S. with resulting economic costs, including: changes in water supply and quality due to changes in drought and extreme rainfall events; increased risk of storm surge and flooding in coastal areas and land loss due to inundation; increases in peak electricity demand and risks to electricity infrastructure; and the potential for significant agricultural disruptions and crop failures (though offset to some extent by carbon fertilization).

There will be important climate benefits associated with the CO_2 emissions reductions expected from this final rule. Climate benefits from reducing emissions of CO_2 can be monetized using estimates of the social cost of carbon (SC-CO_2). See Section 4.4 for more discussion of the approach to monetization of the climate benefits associated with this rule.

ES.6.3 Additional Unquantified Benefits

As stated above, EPA is unable to quantify and monetize the potential benefits of requiring facilities to utilize CEMS rather than continuing to allow the use stack testing, but the requirement has been considered qualitatively. Relative to periodic testing practices, continuous monitoring of fPM will result in increased transparency, as well as potential emissions reductions from identifying problems more rapidly. Hence, the final rule may induce further reductions of fPM and non-Hg HAP metals than we project in this RIA, and these reductions would likely lead to additional health benefits. However, due to data and methodological challenges, EPA is unable to quantify these potential additional reductions. The continuous monitoring of fPM required in this rule is also likely to provide several additional important benefits to the public which are not quantified in this rule, including greater certainty, accuracy, transparency, and granularity in fPM emissions information than exists today. Additionally, to the extent that the CEMS requirement and removal of the second definition of startup leads to actions and emissions impacts that may otherwise not occur absent the amendment in this final rule, there may be beneficial impacts we are unable to estimate.

Regarding the potential health and ecological benefits from HAP emission reductions, data, time, and resource limitations prevent us from quantifying these potential benefits. Additionally, data, time, and resource limitations prevented EPA from quantifying the estimated health impacts or monetizing estimated benefits associated with direct exposure to NO_2 and SO_2 (independent of the role NO_2 and SO_2 play as precursors to $PM_{2.5}$ and ozone), as well as ecosystem effects, and visibility impairment due to the absence of air quality modeling data for these pollutants in this analysis. While all health benefits and welfare benefits were not able to be quantified, it does not imply that there are not additional benefits associated with reductions in exposures to HAP, ozone, $PM_{2.5}$, NO_2 or SO_2.

ES.6.4 Total Benefits

Table ES-4 presents the total monetized health and climate benefits for the final rule.[9] Note the less stringent regulatory alternative only describes the benefits associated with the requirements for PM CEMS qualitatively. As a result, there are no quantified benefits associated with this regulatory option.

Table ES-4 Total Benefits for the Final Rule from 2028 through 2037 (millions of 2019 dollars, discounted to 2023)[a]

		All Values Calculated using 2% Discount Rate	**Health Benefits Calculated using 3% Discount Rate, Climate Benefits Calculated using 2% Discount Rate**	**Health Benefits Calculated using 7% Discount Rate, Climate Benefits Calculated using 2% Discount Rate**
Health Benefits[b]	PV	300	260	180
	EAV	33	31	25
Climate Benefits[c]	PV	130	130	130
	EAV	14	14	14
Total Monetized Benefits	**PV**	**420**	**390**	**300**
	EAV	**47**	**45**	**39**
Non-Monetized Benefits[d]				
Benefits from reductions of about 900 to 1000 pounds of Hg annually				
Benefits from reductions of about 4 to 7 tons of non-Hg HAP metals annually				
Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS				

[a] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.
[b] The estimated value of the air quality-related health benefits reported here are from Table 4-5, Table 4-6, and Table 4-7. Monetized benefits include those related to public health associated with reductions in $PM_{2.5}$ and ozone concentrations. For discussions of the uncertainty associated with these health benefits estimates, see Section 4.3.8.
[c] Monetized climate benefits are based on reductions in CO_2 emissions and are calculated using three different estimates of the social cost of CO_2 (SC-CO_2) (under 1.5 percent, 2.0 percent, and 2.5 percent near-term Ramsey discount rates). For the presentational purposes of this table, we show the climate benefits associated with the SC-CO_2 at the 2 percent near-term Ramsey discount rate. See Table 4-10 for the full range of monetized climate benefit estimates. See Section 4.3.10 for a discussion of the uncertainties associated with the climate benefit estimates.
[d] The list of non-monetized benefits does not include all potential non-monetized benefits. See Table 4-8 for a more complete list.

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[9] Monetized climate benefits are discounted using a 2 percent discount rate, consistent with EPA's updated estimates of the SC-CO_2. OMB has long recognized that climate effects should be discounted only at appropriate consumption-based discount rates. Because the SC-CO_2 estimates reflect net climate change damages in terms of reduced consumption (or monetary consumption equivalents), the use of the social rate of return on capital (7 percent under OMB Circular A-4 (2003)) to discount damages estimated in terms of reduced consumption would inappropriately underestimate the impacts of climate change for the purposes of estimating the SC-CO_2. See Section 4.4 for more discussion.

The estimates of monetized benefits under the final rule are lower than estimated at proposal. While the estimated Hg reductions are higher under the final rule than at proposal, it is important to note that the EPA is unable to quantify the potential benefits of any HAP reductions for this rule. Additionally, while EPA is assuming more filterable PM controls in the final rule, the EPA is unable to quantify the potential benefits of any reductions of non-Hg HAP metals that are expected to result from these controls. Furthermore, because the EPA is no longer projecting any significant change in utilization or capacity at facilities that install additional fPM controls, we do not project major changes in emissions of the criteria and GHG pollutants monetized in the benefit-cost analysis. Consequently, the monetized benefits of the rule are lower than previously projected.

ES.7 Environmental Justice Impacts

EE.O. 12898 directs EPA to identify the populations of concern who are most likely to experience unequal burdens from environmental harms; specifically, minority populations, low-income populations, and Indigenous peoples.[10] Additionally, EE.O. 13985 is intended to advance racial equity and support underserved communities through federal government actions.[11] Most recently, E.O. 14096 (88 FR 25251, April 26, 2023) strengthens the directives for achieving environmental justice that are set out in E.O. 12898. EPA defines environmental justice (EJ) as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. EPA further defines the term fair treatment to mean that "no group of people should bear a disproportionate burden of environmental harms and risks, including those resulting from the negative environmental consequences of industrial, governmental, and commercial operations or programs and policies."[12] In recognizing that minority and low-income populations often bear an unequal burden of environmental harms and risks, EPA continues to consider ways of protecting them from adverse public health and environmental effects of air pollution.

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[10] 59 FR 7629, February 16, 1994.

[11] 86 FR 7009, January 20, 2021.

[12] *https://www.epa.gov/environmentaljustice*.

Environmental justice (EJ) concerns for each rulemaking are unique and should be considered on a case-by-case basis, and EPA's EJ Technical Guidance (2015)[13] states that "[t]he analysis of potential EJ concerns for regulatory actions should address three questions:

1. Are there potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern in the baseline?
2. Are there potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern for the regulatory option(s) under consideration?
3. For the regulatory option(s) under consideration, are potential EJ concerns created or mitigated compared to the baseline?"

To address these questions, EPA developed an analytical approach that considers the purpose and specifics of the rulemaking, as well as the nature of known and potential disproportionate and adverse exposures and impacts. For the rule, we quantitatively evaluate 1) the proximity of affected facilities to potentially vulnerable and/or overburdened populations for consideration of local pollutants impacted by this rule but not modeled here (Section 6.3) and 2) the distribution of ozone and $PM_{2.5}$ concentrations in the baseline and changes due to the rulemaking across different demographic groups on the basis of race, ethnicity, educational attainment, employment status, health insurance status, life expectancy, linguistic isolation, poverty status, redlined areas, tribal land, age, and sex (Section 6.5). It is important to note that due to the small magnitude of underlying emissions changes, and the corresponding small magnitude of the ozone and $PM_{2.5}$ concentration changes, the rule is expected to have only a small impact on the distribution of exposures across each demographic group. We also qualitatively discuss potential EJ HAP and climate impacts (Sections 6.3 and 6.6). Each of these analyses was performed to answer separate questions and is associated with unique limitations and uncertainties. Baseline demographic proximity analyses provide information as to whether there may be potential EJ concerns associated with environmental stressors, such as noise, traffic, and emissions such as NO_2 and SO_2 covered by the regulatory action for certain population groups of concern (Section 6.4). The baseline demographic proximity analyses examined the demographics of populations living within 10 km of the following sources: lignite plants with units potentially impacted by the final Hg standard revision and coal plants with units

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[13] https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis.

potentially impacted by the final fPM standard revision. We evaluated a 5 km radius for the demographic analysis and found it yielded several facilities with zero population within 5 km (i.e., no data) and over 10 percent of the facilities had less than 100 people within 5 km. At a 10-km radius, all facilities but one have population data and only two percent of facilities had less than 100 people within 10 km. Therefore, the 10-km distance was used on the basis that it captures large enough populations to avoid excessive demographic uncertainty.

The baseline analysis indicates that on average the population living within 10 km of coal plants potentially impacted by the final fPM standards shas a higher percentage of people living below two times the poverty level than the national average. In addition, on average the percentage of the Native American population living within 10 km of lignite plants potentially impacted by the final Hg standard is higher than the national average. Relating these results to question 1, above, we conclude that there may be potential EJ concerns associated with directly emitted pollutants that are affected by the regulatory action (e.g., $PM_{2.5}$ and HAP) for certain population groups of concern in the baseline. However, as proximity to affected facilities does not capture variation in baseline exposure across communities, nor does it indicate that any exposures or impacts will occur, these results should not be interpreted as a direct measure of exposure or impact.

As HAP exposure results generated as part of the 2020 MATS RTR were below both the presumptive acceptable cancer risk threshold and the reference dose (RfD), and this final regulation should further reduce exposure to HAP, there is no evidence of ‘disproportionate and adverse effects’ of potential EJ concern. Therefore, we did not perform a quantitative EJ assessment of HAP risk.

In contrast, ozone and $PM_{2.5}$ precursor emission changes that influence ambient concentrations of ozone and $PM_{2.5}$ are also expected from this action, and exposure analyses that evaluate demographic variables are better able to evaluate any potentially disproportionate pollution impacts of this rulemaking. The baseline ozone and $PM_{2.5}$ exposure analyses respond to question 1 from EPA’s EJ Technical Guidance document more directly than the proximity analyses, as they evaluate a form of the environmental stressor affected by the regulatory action (see Section 6.5). $PM_{2.5}$ and ozone exposure analyses show that certain populations, such as residents of redlined census tracts, those who are linguistically isolated, Hispanic individuals, Asian individuals, those without a high school diploma, and the unemployed may experience disproportionately higher ozone and $PM_{2.5}$ exposures in the baseline as compared to the national average. American Indian individuals, residents of Tribal Lands, populations with higher life expectancy or with life expectancy data unavailable, children, and insured populations may also experience disproportionately higher ozone concentrations in the baseline than the reference group. Hispanic individuals, Black individuals, those below the poverty line, and uninsured populations may also experience disproportionately higher $PM_{2.5}$ concentrations in the baseline than the reference group. Therefore, there likely are potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern in the baseline.

Finally, we evaluate how the final rule may be expected to differentially impact demographic populations, informing questions 2 and 3 from EPA's EJ Technical Guidance with regard to ozone and $PM_{2.5}$ exposure changes. Due to the small magnitude of the exposure changes across population demographics associated with the rulemaking relative to the magnitude of the baseline disparities, we infer that disparities in the ozone and $PM_{2.5}$ concentration burdens in the baseline are likely to remain after implementation of the regulatory action or alternatives under consideration. This is due to the small magnitude of the concentration changes associated with this rulemaking across population demographic groups, relative to the magnitude of the baseline disparities (question 2). Also, due to the very small differences observed in the distributional analyses of post-policy ozone and $PM_{2.5}$ exposure impacts across population groups, we do not find evidence that potential EJ concerns related to ozone and $PM_{2.5}$ concentrations will be created or mitigated as compared to the baseline (question 3).

ES.8 Comparison of Benefits and Costs

In this RIA, the regulatory impacts are evaluated for the specific years of 2028, 2030, and 2035. Comparisons of benefits to costs for these snapshot years are presented in Section 7.3 of this RIA. Here we present the PV of costs, benefits, and net benefits, calculated for the years 2028 to 2037 from the perspective of 2023, using two percent, three percent, and seven percent end-of-period discount rate. All dollars are in 2019 dollars. We also present the EAV, which represents a flow of constant annual values that, had they occurred in each year from 2028 to

2037, would yield a sum equivalent to the PV. The EAV represents the value of a typical cost or benefit for each year of the analysis, in contrast to the year-specific estimates reported in the costs and benefits sections of this RIA. The comparison of benefits and costs in PV and EAV terms for the final rule is presented in Table ES-5. The benefits associated with the less stringent regulatory alternative, from the final requirements for PM CEMS are only described qualitatively. As a result, there are no quantified benefits associated with this regulatory option, and we do not include a table reporting the quantified net benefits of that option (the quantified costs are reporting in Table ES-3).

Table ES-5 Projected Net Benefits of the Final Rule (millions of 2019 dollars, discounted to 2023)[a,b]

		Health Benefits[b]		Climate Benefits[c,d]		Compliance Costs			Net Benefits[e]	
Year	**2%**	**3%**	**7%**	**2%**	**2%**	**3%**	**7%**	**2%**	**3%**	**7%**
2028	79	71	52	13	100	99	82	-12	-15	-16
2029	79	71	50	13	100	96	77	-10	-13	-13
2030	27	24	16	-7.1	100	95	73	-82	-78	-64
2031	27	24	16	-7.1	100	92	68	-80	-76	-60
2032	14	13	8	19	79	73	52	-46	-41	-24
2033	14	13	8	19	78	71	48	-44	-39	-21
2034	14	12	7.3	19	76	69	45	-43	-37	-19
2035	14	12	7.0	19	75	67	42	-41	-35	-16
2036	14	12	6.7	19	73	65	39	-40	-33	-14
2037	14	12.0	6.4	19	72	63	37	-39	-32	-11
		Health Benefits[b]		**Climate Benefits[c]**		**Compliance Costs**			**Net Benefits[e]**	
						Discount Rate				
	2%	**3%**	**7%**	**2%**	**2%**	**3%**	**7%**	**2%**	**3%**	**7%**
PV	**300**	**260**	**180**	**130**	**860**	**790**	**560**	**-440**	**-400**	**-260**
EAV	**33**	**31**	**25**	**14**	**96**	**92**	**80**	**-49**	**-47**	**-41**

Non-Monetized Benefits[e]
Benefits from reductions of about 900 to 1000 pounds of Hg annually
Benefits from reductions of about 4 to 7 tons of non-Hg HAP metals annually
Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

[a] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

[b] The estimated value of the air quality-related health benefits reported here are the larger of the two estimates presented in Table 4-5, Table 4-6, and Table 4-7. Monetized benefits include those related to public health associated with reductions in $PM_{2.5}$ and ozone concentrations. For discussions of the uncertainty associated with these health benefits estimates, see Section 4.3.8.

[c] Monetized climate benefits are based on reductions in CO_2 emissions and are calculated using three different estimates of the social cost of CO_2 (SC-CO_2) (under 1.5 percent, 2.0 percent, and 2.5 percent near-term Ramsey discount rates). For the presentational purposes of this table, we show the climate benefits associated with the SC-CO_2 at the 2 percent near-term Ramsey discount rate. See Table 4-10 for the full range of monetized climate benefit estimates.

[d] The small increases and decreases in climate and health benefits and related EJ impacts result from very small changes in fossil dispatch and coal use relative to the baseline. For context, the projected increase in CO_2 emission of less than 40,000 tons in 2030 is roughly one percent of the emissions of a mid-size coal plant operating at availability (about 4 million tons).

[e] The list of non-monetized benefits does not include all potential non-monetized benefits. See Table 4-8 for a more complete list.

The monetized estimates of benefits presented in this section are underestimated because important categories of benefits, including benefits from reducing Hg and non-Hg HAP metals emissions and the increased transparency, compliance assurance, and accelerated identification of anomalous emissions anticipated from requiring PM CEMS, were not monetized in our analysis. Simultaneously, the estimates of compliance costs used in the net benefits analysis may provide an incomplete characterization of the true costs of the rule. We nonetheless consider these potential impacts in our evaluation of the net benefits of the rule. As the EPA no longer projects incremental facility retirement and expects less change in capacity and utilization, higher compliance costs are expected along with smaller monetized benefits than in the proposal analysis of this rulemaking. The result of combining those updated estimates is a lower estimate of net benefits than in the proposal analysis.

ES.9 References

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INTRODUCTION AND BACKGROUND

1.1 Introduction

Exposure to hazardous air pollution ("HAP," sometimes known as toxic air pollution, including Hg, chromium, arsenic, and lead) can cause a range of adverse health effects including harming people's central nervous system; damaging their kidneys; and causing cancer. Recognizing the dangers posed by HAP, Congress enacted Clean Air Act (CAA) section 112. Under CAA section 112, the Environmental Protection Agency (EPA) is required to set standards (known as "MACT" (maximum achievable control technology) standards) for major sources of HAP that "require the maximum degree of reduction in emissions of the hazardous air pollutants . . . (including a prohibition on such emissions, where achievable) that the Administrator, taking into consideration the cost of achieving such emission reduction, and any non-air quality health and environmental impacts and energy requirements, determines is achievable." 42 U.S.C. 7412(d)(2). On January 20, 2021, President Biden signed EE.O. 13990, "Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis" (86 FR 7037; January 25, 2021). The executive order, among other things, instructed EPA to review the 2020 final rule titled "National Emission Standards for Hazardous Air Pollutants: Coal- and Oil- Fired Electric Utility Steam Generating Units—Reconsideration of Supplemental Finding and Residual Risk and Technology Review" (85 FR 31286; May 22, 2020) and to consider publishing a notice of proposed rulemaking suspending, revising, or rescinding that action. The 2020 Final Action included a finding that it is not appropriate and necessary to regulate coal- and oil-fired EGUs under CAA section 112 as well as the RTR for the MATS rule. The results of EPA's review of the 2020 appropriate and necessary finding were proposed on February 9, 2022 (87 FR 7624) (2022 Proposal) and finalized on March 6, 2023 (88 FR 13956). In the 2022 Proposal, EPA also solicited information on the performance and cost of new or improved technologies that control HAP emissions, improved methods of operation, and risk-related information to further inform EPA's review of the 2020 MATS RTR. The review of the RTR was proposed on April 24, 2023 (88 FR 24854) and this action presents the final results of EPA's review of the MATS RTR. This RIA presents the expected economic consequences of EPA's final MATS Risk and Technology Review.

Several statutes and executive orders apply to federal rulemakings. In accordance with E.O. 12866 and E.O. 14094 and the guidelines of OMB Circular A-4, the RIA presents the benefits and costs associated with the projected emissions reductions under the final rule.[14] The benefits and costs of the final rule and regulatory alternative are presented for the 2028 to 2037 time period. The estimated monetized benefits are those health benefits expected to arise from reduced $PM_{2.5}$ and ozone concentrations and the climate benefits from reductions in GHGs. Several categories of benefits remain unmonetized including important benefits from reductions in Hg and non-Hg HAP metal emissions. The estimated monetized costs for EGUs are the costs of installing and operating controls and the increased costs of producing electricity. Unquantified benefits and costs are described qualitatively. This section contains background information relevant to the rule and an outline of the sections of this RIA.

1.2 Legal and Economic Basis for Rulemaking

In this section, we summarize the statutory requirements in the CAA that serve as the legal basis for the final rule and the economic theory that supports environmental regulation as a mechanism to enhance social welfare. The CAA requires EPA to prescribe regulations for new and existing sources. In turn, those regulations attempt to address negative externalities created when private entities fail to internalize the social costs of air pollution.

1.2.1 Statutory Requirement

The statutory authority for this action is provided by sections 112 and 301 of the CAA, as amended (42 U.S.C. 7401 et seq.). Section 112 of the CAA establishes a two-stage regulatory process to develop standards for emissions of HAP from stationary sources. Generally, the first stage involves establishing technology-based standards and the second stage involves evaluating those standards that are based on maximum achievable control technology (MACT) to determine whether additional standards are needed to address any remaining risk associated with HAP emissions. This second stage is commonly referred to as the "residual risk review." In addition to the residual risk review, the CAA also requires EPA to review standards set under CAA section

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[14] Circular A-4 was recently revised. The effective date of the revised Circular A-4 (2023) is March 1, 2024, for regulatory analyses received by OMB in support of proposed rules, interim final rules, and direct final rules, and January 1, 2025, for regulatory analyses received by OMB in support of other final rules. For all other rules, Circular A-4 (2003) is applicable until those dates.

112 no less than every eight years and revise the standards as necessary taking into account any "developments in practices, processes, or control technologies." This review is commonly referred to as the "technology review," and is the subject of this rulemaking.

1.2.2 Regulated Pollutants

For coal-fired EGUs, the 2012 MATS rule established standards to limit emissions of Hg, acid gas HAP, non-Hg HAP metals (e.g., nickel, lead, chromium), and organic HAP (e.g., formaldehyde, dioxin/furan). Standards for hydrochloric acid (HCl) serve as a surrogate for the acid gas HAP, with an alternate standard for sulfur dioxide (SO_2) that may be used as a surrogate for acid gas HAP for those coal-fired EGUs with flue gas desulfurization (FGD) systems and SO_2 CEMS installed and operational. Standards for fPM serve as a surrogate for the non-Hg HAP metals, with standards for total non-Hg HAP metals and individual non-Hg HAP metals provided as alternative equivalent standards. Work practice standards limit formation and emission of the organic HAP.

For oil-fired EGUs, the 2012 MATS rule established standards to limit emissions of HCl and hydrogen fluoride (HF), total HAP metals (e.g., Hg, nickel, lead), and organic HAP (e.g., formaldehyde, dioxin/furan). Standards for fPM serve as a surrogate for total HAP metals, with standards for total HAP metals and individual HAP metals provided as alternative equivalent standards. Work practice standards limit formation and emission of the organic HAP.

1.2.2.1 Definition of Affected Source

The source category that is the subject of this final rule is Coal- and Oil-Fired EGUs regulated under 40 CFR 63, subpart UUUUU. The North American Industry Classification System (NAICS) codes for the Coal- and Oil-fired EGU industry are 221112, 221122, and 921150. This list of categories and NAICS codes is not intended to be exhaustive, but rather provides a guide for readers regarding the entities that this action is likely to affect. The final standards will be directly applicable to the affected sources. Federal, state, local, and tribal government entities that own and/or operate EGUs subject to 40 CFR part 63, subpart UUUUU would be affected by this action. The Coal- and Oil-Fired EGU source category was added to the list of categories of major and area sources of HAP published under section 112(c) of the CAA on December 20, 2000 (65 FR 79825). CAA section 112(a)(8) defines an EGU as: any fossil fuel fired combustion unit of more than 25 MW that serves a generator that produces electricity for sale. A unit that cogenerates steam and electricity and supplies more than one-third of its potential electric output capacity and more than 25 MW electrical output to any utility power distribution system for sale is also considered an EGU.

1.2.3 The Potential Need for Regulation

OMB Circular A-4 indicates that one of the reasons a regulation may be issued is to address a market failure. The major types of market failure include externalities, market power, and inadequate or asymmetric information. Correcting market failures is one reason for regulation; it is not the only reason. Other possible justifications include improving the function of government, correcting distributional unfairness, or securing privacy or personal freedom.

Environmental problems are classic examples of externalities – uncompensated benefits or costs imposed on another party as a result of one's actions. For example, the smoke from a factory may adversely affect the health of local residents and soil the property in nearby neighborhoods. For the regulatory action analyzed in this RIA, the good produced is electricity from coal- and oil-fired EGUs. If these electricity producers pollute the atmosphere when generating power, the social costs will not be borne exclusively by the polluting firm but rather by society as a whole. Thus, the producer is imposing a negative externality, or a social cost of emissions, on society. The equilibrium market price of electricity may fail to incorporate the full opportunity cost to society of these products. Consequently, absent a regulation on emissions, producers will not internalize the social cost of emissions and social costs will be higher as a result. This regulation will work towards addressing this market failure by causing affected producers to begin internalizing the negative externality associated with HAP emissions from electricity generation by coal- and oil-fired EGUs.

1.3 Overview of Regulatory Impact Analysis

1.3.1 Regulatory Options

This RIA focuses on four amendments to the MATS rule, which are described in more detail in this section.

1.3.1.1 Filterable Particulate Matter Standards for Existing Coal-fired EGUs

Existing coal-fired EGUs are subject to numeric emission limits for fPM, a surrogate for the total non-Hg HAP metals.[15] Before this final rule, MATS required existing coal-fired EGUs to meet a fPM emission standard of 0.030 pounds per million British thermal units (lb/MMBtu) of heat input. The standards for fPM serve as a surrogate for standards for non-Hg HAP metals. After reviewing updated information on the current emission levels of fPM from existing coal-fired EGUs and the costs of meeting a standard more stringent than 0.030 lb/MMBtu, EPA is revising the fPM emission standard for existing coal-fired EGUs to 0.010 lb/MMBtu. Additionally, EPA is finalizing updated limits for non-Hg metals and total non-Hg metals that have been reduced proportional to the reduction of the fPM emission limit. EGU owners or operators who would choose to comply with the non-Hg HAP metals emission limits instead of the fPM limit must request and receive approval of a non-Hg HAP metal continuous monitoring system as an alternative test method (e.g., multi-metal continuous monitoring system) under the provisions of 40 CFR 63.7(f).

1.3.1.2 Hg Emission Standard for Lignite-fired EGUs

EPA is revising the Hg emission standard for lignite-fired EGUs. Before this final rule, lignite-fired EGUs were required to meet a Hg emission standard of 4.0 pounds per trillion British thermal units (lb/TBtu) or 4.0E-2 pounds per gigawatt hour (lb/GWh). EPA recently collected information on current emission levels and Hg emission controls for lignite-fired EGUs using the authority provided under CAA section 114.[16] That information showed that many units are able to achieve a Hg emission rate that is much lower than the current standard, and there are cost-effective control technologies and methods of operation that are available to achieve a more

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[15] As described in section III of the preamble to 2023 proposal, EGUs in seven subcategories are subject to numeric emission limits for specific HAP or fPM, a surrogate for the total non-mercury HAP metals. The fPM was chosen as a surrogate in the original rulemaking because the non-mercury HAP metals are predominantly a component of PM, and control of PM will also result in co-reduction of non-mercury HAP metals. Additionally, not all fuels emit the same type and amount of HAP metals, but most generally emit PM that include some amount and combination of all the HAP metals. Lastly, the use of fPM as a surrogate eliminates the cost of performance testing to comply with numerous standards for individual non-mercury HAP metals (Docket ID No. EPA-HQ-OAR-2009-0234). For these reasons, EPA focused its review on the fPM emissions of coal-fired EGUs as a surrogate for the non-mercury HAP metals.

[16] For further information, see EPA memorandum titled "2024 Update to the 2023 Proposed Technology Review for the Coal- and Oil-Fired EGU Source Category" which is available in the docket.

stringent standard. EPA is finalizing a standard for lignite-fired EGUs of 1.2 lb/TBtu or 1.3E-2 lb/GWh, the same standard applied to EGUs firing other types of coal.

1.3.1.3 Require that All Coal- and Oil-Fired EGUs Demonstrate Compliance with the fPM Emission Standard by Using PM CEMS

In addition to revising the PM emission standard for existing coal-fired EGUs, EPA is revising the requirements for demonstrating compliance with the PM emission standard for coal- and oil-fired EGUs. Before this final rule, EGUs that were not part of the low-emitting EGU (LEE) program could demonstrate compliance with the fPM standard either by conducting performance testing quarterly or by using PM CEMS. After considering updated information on the costs for performance testing, the costs of PM CEMS, the capabilities of PM CEMS measurement abilities, and the benefits of using PM CEMS, including increased transparency, compliance assurance, and accelerated identification of anomalous emissions, EPA is requiring that all coal- and oil-fired fired EGUs demonstrate compliance with the PM emission standard by using PM CEMS. EPA proposed to require PM CEMS for existing IGCC EGUs but is not finalizing this requirement due to technical issues calibrating CEMS on these types of EGUs and the related fact that fPM emissions from IGCCs are very low.

1.3.1.4 Startup Definitions

Finally, separate from the technology review, EPA is removing one of the two options for defining the startup period for EGUs. The first option defines startup as either the first-ever firing of fuel in a boiler for the purpose of producing electricity, or the firing of fuel in a boiler after a shutdown event for any purpose. Startup ends when any of the steam from the boiler is used to generate electricity for sale over the grid or for any other purpose (including on-site use). In the second option, startup is defined as the period in which operation of an EGU is initiated for any purpose. Startup begins with either the firing of any fuel in an EGU for the purpose of producing electricity or useful thermal energy (such as heat or steam) for industrial, commercial, heating, or cooling purposes (other than the first-ever firing of fuel in a boiler following construction of the boiler) or for any other purpose after a shutdown event. Startup ends four hours after the EGU generates electricity that is sold or used for any other purpose (including on-site use), or four hours after the EGU makes useful thermal energy (such as heat or steam) for industrial, commercial, heating, or cooling purposes, whichever is earlier. EPA is removing the second option, which is currently being used by fewer than 10 EGUs.

1.3.1.5 Summary of Regulatory Options Examined in this RIA

Table 1-1 summarizes how we have structured the regulatory options to be analyzed in this RIA. The final regulatory option includes the amendments just discussed in this section: the revision to the fPM standard to 0.010 lb/MMBtu, in which fPM is a surrogate for non-Hg HAP metals, the revision to the Hg standard for lignite-fired EGUs to 1.2 lb/TBtu, the requirement to use PM CEMS to demonstrate compliance, and the removal of the startup definition number two. The less stringent regulatory option examined in this RIA assumed the PM and Hg limits remain unchanged and examines just the PM CEMS requirement and removal of startup definition number two.

Table 1-1 Summary of Regulatory Options Examined in this RIA

	Regulatory Options Examined in this RIA	
Provision	**Less Stringent**	**Final Rule**
FPM Standard (Surrogate Standard for Non-Hg HAP Metals)	Retain existing fPM standard of 0.030 lb/MMBtu	Revised fPM standard of 0.010 lb/MMBtu
Hg Standard	Retain Hg standard for lignite-fired EGUs of 4.0 lb/TBtu	Revised Hg standard for lignite-fired EGUs of 1.2 lb/TBtu
Continuous Emissions Monitoring Systems (PM CEMS)	Require installation of PM CEMS to demonstrate compliance	Require installation of PM CEMS to demonstrate compliance
Startup Definition	Remove startup definition #2	Remove startup definition #2

The compliance date for affected coal-fired sources to comply with the revised fPM limit of 0.010 lb/MMBtu and for lignite-fired sources to meet with the lower Hg limit of 1.2 lb/Tbtu is three years after the effective date of the final rule. EPA is finalizing the requirement that affected sources use PM CEMS for compliance demonstration by three years after the effective date of the final rule. The compliance date for existing affected sources to comply with amendments pertaining to the startup definition is 180 days after the effective date of the final rule.

Both the final rule and less stringent options described in Table 1-1 have not been changed from the proposed and less stringent options examined in the RIA for the proposal of this action. The proposal RIA included a more stringent regulatory option that projected the impacts of lowering the fPM standard to 0.006 lb/MMBtu, while holding the other three proposed amendments unchanged from the proposed option. As explained in the preamble of the final rule, EPA determined not to pursue a more stringent standard for fPM emissions, such as a limit of 0.006 lb/MMBtu. After considering comments to the proposed rule and conducting additional analysis, EPA determined that a fPM standard lower than 0.010 lb/MMBtu would not be compatible with PM CEMS due to measurement uncertainty. While a fPM emission limit of 0.006 lb/MMBtu may appear to be more stringent than the 0.010 lb/MMBtu standard that the EPA is finalizing in this rule, there is no way to confirm emission reductions during periods where emission rates may be higher. Therefore, the Agency is finalizing a fPM limit of 0.010 lb/MMBtu with the use of PM CEMS as the only means of compliance demonstration. The EPA has determined that this combination of fPM limit and compliance demonstration represents the most stringent option taking into account the statutory considerations.

1.3.2 Baseline and Analysis Years

The impacts of regulatory actions are evaluated relative to a baseline that represents the world without the action. This version of the model ("EPA's Power Sector Modeling Platform 2023") used for the baseline in this RIA includes recent updates to state and federal legislation affecting the power sector, including Public Law 117-169, 136 Stat. 1818 (August 16, 2022), commonly known as the Inflation Reduction Act of 2022 (IRA). The modeling documentation includes a summary of all legislation reflected in this version of the model as well as a description of how that legislation is implemented in the model.[17] Also, see Section 3.3 for additional detail about the power sector baseline for this RIA.

The year 2028 is the first year of detailed power sector modeling for this RIA and approximates when the regulatory impacts of the final rule on the power sector will begin.[18,19] In

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[17] Documentation for EPA's Power Sector Modeling Platform 2023 using IPM can be found at *https://www.epa.gov/power-sector-modeling* and is available in the docket for this action. For information regarding inclusion of the IRA in the baseline, see section 3.10.4 and 4.5.

[18] Note that the Agency has granted the maximum time allowed for compliance under CAA section 112(i)(3) of three years, and individual facilities may seek, if warranted, an additional 1-year extension of the compliance from their permitting authority pursuant to CAA section 112(i)(3)(B). Facilities may also request, if warranted, emergency authority to operate through the Department of Energy under section 202(c) of the Federal Power Act.

[19] We note that, while the compliance date of the rule will likely be mid- to late-2027 and all compliance costs are accounted for, any emissions reductions and benefits that in occur over a few months in 2027 are omitted from this analysis.

addition, the regulatory impacts are evaluated for the specific analysis years of 2030 and 2035. These results are used to estimate the PV and EAV of the 2028 through 2037 period.

1.4 Organization of the Regulatory Impact Analysis

This RIA is organized into the following remaining sections:

- **Section 2: Power Sector Industry Profile.** This section describes the electric power sector in detail.
- **Section 3: Cost, Emissions, and Energy Impacts.** The section summarizes the projected compliance costs and other energy impacts associated with the regulatory options.
- **Section 4: Benefits Analysis.** The section presents the projected health and environmental benefits of reductions in emissions of HAP, direct $PM_{2.5}$, and $PM_{2.5}$ and ozone precursors and the climate benefits of CO_2 emissions reductions across regulatory options.
- **Section 5: Economic Impacts.** The section includes a discussion of potential small entity, economic, and labor impacts.
- **Section 6: Environmental Justice Impacts.** This section includes an assessment of potential impacts to potential EJ populations.
- **Section 7: Comparison of Benefits and Costs.** The section compares of the total projected benefits with total projected costs and summarizes the projected net benefits of the three regulatory options examined. The section also includes a discussion of potential benefits that EPA is unable to quantify and monetize.

1.5 References

OMB. (2003). Circular A-4: Regulatory Analysis. Washington DC. https://www.whitehouse.gov/wp-content/uploads/legacy_drupal_files/omb/circulars/A4/a-4.pdf

OMB. (2023). Circular A-4: Regulatory Analysis. Washington DC. https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf

INDUSTRY PROFILE

2.1 Background

In the past decade, there have been substantial structural changes in both the mix of generating capacity and in the share of electricity generation supplied by different types of generation. These changes are the result of multiple factors in the power sector, including replacements of older generating units with new units, changes in the electricity intensity of the U.S. economy, growth and regional changes in the U.S. population, technological improvements in electricity generation from both existing and new units, changes in the prices and availability of different fuels, and substantial growth in electricity generation from renewable energy sources. Many of these trends will likely continue to contribute to the evolution of the power sector.[20] The evolving economics of the power sector, specifically the increased natural gas supply and subsequent relatively low natural gas prices, have resulted in more natural gas being used to produce both base and peak load electricity. Additionally, rapid growth in the deployment of wind and solar technologies has led to their now constituting a significant share of generation. The combination of these factors has led to a decline in the share of electricity generated from coal. This section presents data on the evolution of the power sector over the past two decades from 2010 through 2022, as well as a focus on the period 2015 through 2022. Projections of future power sector behavior and the projected impacts of the final rule are discussed in more detail in Section 3 of this RIA.

2.2 Power Sector Overview

The production and delivery of electricity to customers consists of three distinct segments: generation, transmission, and distribution.

2.2.1 Generation

Electricity generation is the first process in the delivery of electricity to consumers. There are two important aspects of electricity generation: capacity and net generation. *Generating Capacity* refers to the maximum amount of production an EGU is capable of producing in a

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[20] For details on the evolution of EPA's power sector projections, please see archive of IPM outputs available at: *epa.gov/power-sector-modeling*.

typical hour, typically measured in megawatts (MW) for individual units, or gigawatts (1 GW = 1000 MW) for multiple EGUs. *Electricity Generation* refers to the amount of electricity actually produced by an EGU over some period of time, measured in kilowatt-hours (kWh) or gigawatt-hours (1 GWh = 1 million kWh). *Net Generation* is the amount of electricity that is available to the grid from the EGU (i.e., excluding the amount of electricity generated but used within the generating station for operations). Electricity generation is most often reported as the total annual generation (or some other period, such as seasonal). In addition to producing electricity for sale to the grid, EGUs perform other services important to reliable electricity supply, such as providing backup generating capacity in the event of unexpected changes in demand or unexpected changes in the availability of other generators. Other important services provided by generators include facilitating the regulation of the voltage of supplied generation.

Individual EGUs are not used to generate electricity 100 percent of the time. Individual EGUs are periodically not needed to meet the regular daily and seasonal fluctuations of electricity demand. Units are also unavailable during routine and unanticipated outages for maintenance. Furthermore, EGUs relying on renewable resources such as wind, sunlight, and surface water to generate electricity are routinely constrained by the availability of adequate wind, sunlight, or water at different times of the day and season. These factors result in the share of potential generating capacity being substantially different from the share of actual electricity produced by each type of EGU in a given season or year.

Most of the existing capacity generates electricity by creating heat to create high pressure steam that is released to rotate turbines which, in turn, create electricity. Natural gas combined cycle (NGCC) units have two generating components operating from a single source of heat. The first cycle is a gas-fired combustion turbine, which generates electricity directly from the heat of burning natural gas. The second cycle reuses the waste heat from the first cycle to generate steam, which is then used to generate electricity from a steam turbine. Other EGUs generate electricity by using water or wind to rotate turbines, and a variety of other methods including direct photovoltaic generation also make up a small, but growing, share of the overall electricity supply. The most common generating capacity includes fossil-fuel-fired units, nuclear units, and hydroelectric and other renewable sources (see Table 2-1 and Table 2-2). Table 2-1 and Table 2-2 also show the comparison between the generating capacity in 2010 to 2022 and 2015 to 2022, respectively.

In 2022 the power sector comprised a total capacity[21] of 1,201 GW, an increase of 162 GW (or 16 percent) from the capacity in 2010 (1,039 GW). The largest change over this period was the decline of 127 GW of coal capacity, reflecting the retirement/rerating of close to 40 percent of the coal fleet. This reduction in coal capacity was offset by increases in natural gas, solar, and wind capacities of 95 GW, 72 GW, and 102 GW respectively. Substantial amounts of distributed solar (40 GW) were also added.

These trends persist over the shorter 2015-21 period as well; total capacity in 2022 (1,201 GW) increased by 127 GW (or 12 percent). The largest change in capacity was driven by a reduction of 90 GW of coal capacity. This was offset by a net increase of 63 GW of natural gas capacity, an increase of 69 GW of wind, and an increase of 59 GW of solar. Additionally, 30 GW of distributed solar were also added over the 2015-22 period.

Table 2-1 Total Net Summer Electricity Generating Capacity by Energy Source, 2010-2022

	2010		2022		Change Between '10 and '22	
Energy Source	**Net Summer Capacity (GW)**	**% Total Capacity**	**Net Summer Capacity (GW)**	**Net Summer Capacity (GW)**	**% Total Capacity**	**Net Summer Capacity (GW)**
Coal	317	30%	189	16%	-40%	-127
Natural Gas	407	39%	502	42%	23%	95
Nuclear	101	10%	95	8%	-6%	-7
Hydro	101	10%	103	9%	2%	2
Petroleum	56	5%	31	3%	-45%	-25
Wind	39	4%	141	12%	261%	102
Solar	1	0%	73	6%	8310%	72
Distributed Solar	0	0%	40	3%		40
Other Renewable	14	1%	15	1%	7%	1
Misc	4	0%	12	1%	239%	9
Total	1,039	100%	1,201	100%	16%	162

Source: EIA. Electric Power Annual 2022, Table 3.1.A and 3.1.B

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[21] This includes generating capacity at EGUs primarily operated to supply electricity to the grid and combined heat and power facilities classified as Independent Power Producers (IPP) and excludes generating capacity at commercial and industrial facilities that does not operate primarily as an EGU. Natural Gas information in this section (unless otherwise stated) reflects data for all generating units using natural gas as the primary fossil heat source. This includes Combined Cycle Combustion Turbine, Gas Turbine, steam, and miscellaneous (< 1 percent).

Table 2-2 Total Net Summer Electricity Generating Capacity by Energy Source, 2015-2022

	2015		2022		Change Between '15 and '22	
Energy Source	**Net Summer Capacity (GW)**	**% Total Capacity**	**Net Summer Capacity (GW)**	**% Total Capacity**	**% Increase**	**Capacity Change (GW)**
Coal	280	26%	189	16%	-32%	-90
Natural Gas	439	41%	502	42%	14%	63
Nuclear	99	9%	95	8%	-4%	-4
Hydro	102	10%	103	9%	1%	1
Petroleum	37	3%	31	3%	-16%	-6
Wind	73	7%	141	12%	95%	69
Solar	14	1%	73	6%	433%	59
Distributed Solar	10	1%	40	3%	307%	30
Other Renewable	17	2%	15	1%	-11%	-2
Misc	4	0%	12	1%	182%	8
Total	1,074	100%	1,201	100%	12%	127

Source: EIA. Electric Power Annual 2022, Table 3.1.A and 3.1.B

The average age of coal-fired power plants that retired between 2015 and 2023 was over 50 years. Older power plants tend to become uneconomic over time as they become more costly to maintain and operate, and as newer and more efficient alternative generating technologies are built. As a result, coal's share of total U.S. electricity generation has been declining for over a decade, while generation from natural gas and renewables has increased significantly.[22] As shown in Figure 2-1 below, 70 percent of the coal fleet in 2023 had an average age of over 40 years.

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[22] EIA, Today in Energy (April 17, 2017) available at *https://www.eia.gov/todayinenergy/detail.php?id=30812*.

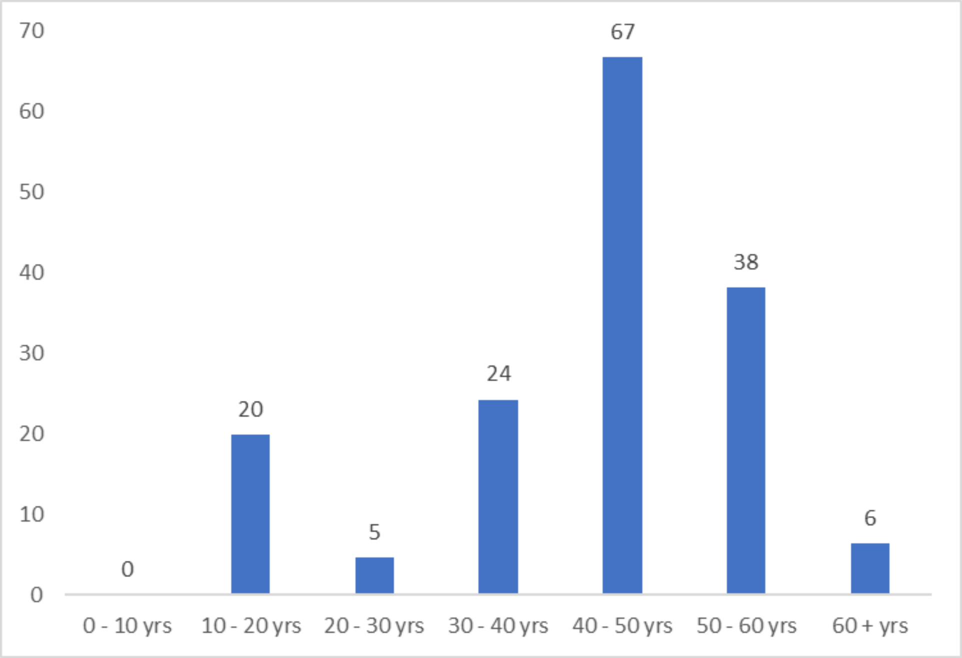

Figure 2-1 National Coal-fired Capacity (GW) by Age of EGU, 2023
Source: NEEDS v6

In 2022, electric generating sources produced a net 4,292 TWh to meet national electricity demand, which was around 4 percent higher than 2010. As presented in Table 2-2, 60 percent of electricity in 2022 was produced through the combustion of fossil fuels, primarily coal and natural gas, with natural gas accounting for the largest single share. The total generation share from fossil fuels in 2022 (60 percent) was 10 percent less than the share in 2010 (70 percent). Moreover, the share of fossil generation supplied by coal fell from 65 percent in 2010 to 33 percent by 2022, while the share of fossil generation supplied by natural gas rose from 35 percent to 67 percent over the same period. In absolute terms, coal generation declined by 55 percent, while natural gas generation increased by 71 percent. This reflects both the increase in natural gas capacity during that period as well as an increase in the utilization of new and existing gas EGUs during that period. The combination of wind and solar generation also grew from 2 percent of the mix in 2010 to 14 percent in 2022.

Table 2-3 Net Generation by Energy Source, 2010 to 2022 (Trillion kWh = TWh)

	2010		2022		Change Between '10 and '22	
Energy Source	**Net Generation (TWh)**	**Fuel Source Share**	**Net Generation (TWh)**	**Fuel Source Share**	**% Increase**	**Generation Change (TWh)**
Coal	1,847	45%	832	19%	-55%	-1,016
Natural Gas	988	24%	1,687	39%	71%	699
Nuclear	807	20%	772	18%	-4%	-35
Hydro	255	6%	249	6%	-2%	-6
Petroleum	37	1%	23	1%	-38%	-14
Wind	95	2%	434	10%	359%	340
Solar	1	0%	144	3%	11764%	143
Distributed Solar	0	0%	61	1%		61
Other Renewable	71	2%	68	2%	-5%	-3
Misc	24	1%	23	1%	-6%	-1
Total	4,125	100%	4,292	100%	4%	167

Table 2-4 Net Generation by Energy Source, 2015 to 2022 (Trillion kWh = TWh)

	2015		2022		Change Between '15 and '22	
Energy Source	**Net Generation (TWh)**	**Fuel Source Share**	**Net Generation (TWh)**	**Fuel Source Share**	**% Increase**	**Generation Change (TWh)**
Coal	1,352	33%	832	19%	-39%	-521
Natural Gas	1,335	33%	1,687	39%	27%	354
Nuclear	797	19%	772	18%	-3%	-26
Hydro	249	6%	249	6%	2%	5
Petroleum	28	1%	23	1%	-19%	-5
Wind	191	5%	434	10%	128%	244
Solar	25	1%	144	3%	478%	119
Distributed Solar	14	0%	61	1%	333%	47
Other Renewable	80	2%	68	2%	-15%	-12
Misc	27	1%	23	1%	-16%	-4
Total	4,092	100%	4,292	100%	5%	200

Coal-fired and nuclear generating units have historically supplied “base load” electricity, meaning that these units operate through most hours of the year and serve the portion of electricity load that is continually present. Although much of the coal fleet has historically operated as base load, there can be notable differences in the design of various facilities (see Table 2-3 and Table 2-4) which, along with relative fuel prices, can impact the operation of coal-fired power plants. As one example of design variations, coal-fired units less than 100 MW in size comprise 17 percent of the total number of coal-fired units, but only 2 percent of total coal-fired capacity, and they tend to have higher heat rates. Gas-fired generation is generally better able to vary output, is a primary option used to meet the variable portion of the electricity load and has historically supplied “peak” and “intermediate” power, when there is increased demand for electricity (for example, when businesses operate throughout the day or when people return home from work and run appliances and heating/air-conditioning), versus late at night or very early in the morning, when demand for electricity is reduced. Over the last decade, however, the generally low price of natural gas and the growing age of the coal fleet has resulted in increasing capacity factors for many gas-fired plants and decreasing capacity factors for many coal-fired plants. As shown in Figure 2-2, average annual coal capacity factors have declined from 67 percent to 50 percent over the 2010 to 2022 period, indicating that a larger share of units are operating in non-baseload fashion. Over the same period, natural gas combined cycle capacity factors have risen from an annual average of 44 percent to 57 percent.

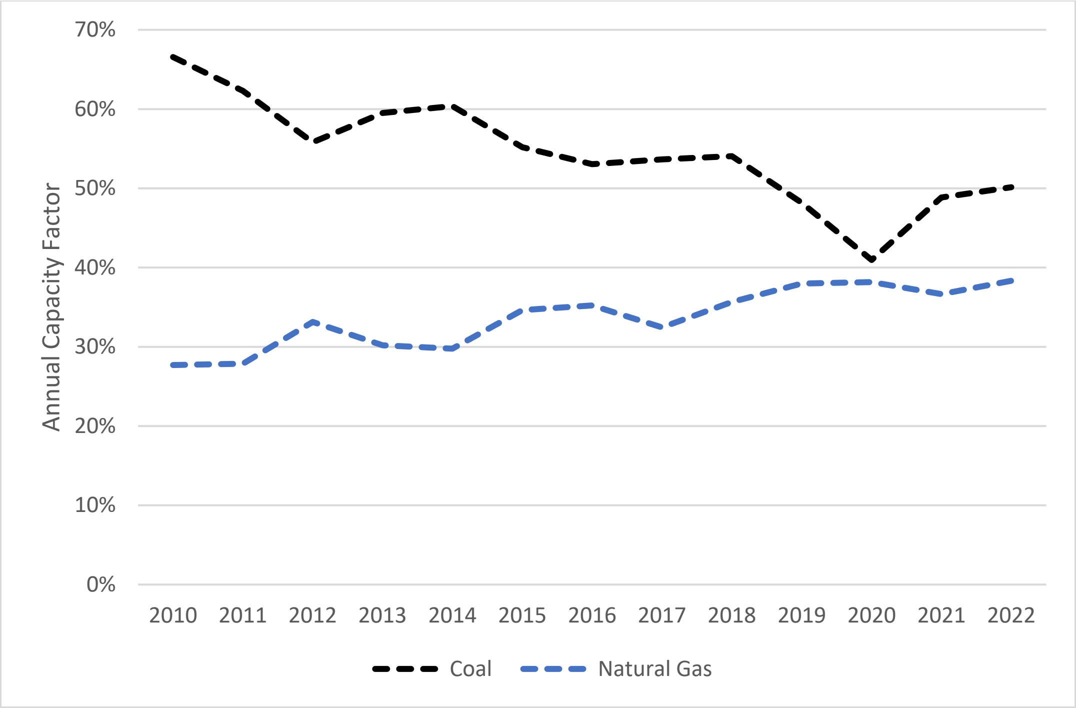

Figure 2-2 Average Annual Capacity Factor by Energy Source
Source: EIA. Electric Power Annual 2022 Table 4.08.A

Table 2-5 also shows comparable data for the capacity and age distribution of coal and natural gas units. Compared with the fleet of coal EGUs, the natural gas fleet of EGUs is generally smaller and newer. While 69 percent of the coal EGU fleet capacity is over 500 MW per unit, 82 percent of the gas fleet is between 50 and 500 MW per unit.

Table 2-5 Coal and Natural Gas Generating Units, by Size, Age, Capacity, and Average Heat Rate in 2023

Unit Size Grouping (MW)	No. Units	% of All Units	Avg. Age	Avg. Net Summer Capacity (MW)	Total Net Summer Capacity (MW)	% Total Capacity	Avg. Heat Rate (Btu/kWh)
COAL							
0 – 24	17	4%	56	13	218	0%	12,103
25 – 49	27	7%	37	36	978	1%	11,739
50 – 99	20	5%	32	76	1,510	1%	11,858
100 – 149	24	6%	52	120	2,869	2%	11,195
150 – 249	38	10%	47	195	7,394	5%	10,809
250 – 499	95	25%	42	379	36,008	23%	10,660
500 – 749	104	28%	41	612	63,604	40%	10,243
750 – 999	44	12%	39	818	35,979	22%	10,167
1000 – 1500	9	2%	46	1,264	11,380	7%	9,813
Total Coal	378	100%	42	423	159,940	100%	10,722
NATURAL GAS							
0 – 24	4,679	56%	30	4	20,963	4%	13,006
25 – 49	899	11%	26	41	36,619	7%	11,545
50 – 99	1,000	12%	29	72	71,611	14%	12,194
100 – 149	391	5%	26	125	48,863	10%	9,548
150 – 249	1,037	12%	20	180	186,503	37%	8,194
250 – 499	309	4%	21	330	101,969	20%	8,072
500 – 749	47	1%	30	585	27,495	5%	9,374
750 – 999	8	0%	47	838	6,706	1%	11,366
1000 – 1500	0	0%			0	0%	
Total Gas	8,362	100%	27	60	500,730	100%	11,790

Source: National Electric Energy Data System (NEEDS) v.6
Note: The average heat rate reported is the mean of the heat rate of the units in each size category (as opposed to a generation-weighted or capacity-weighted average heat rate.) A lower heat rate indicates a higher level of fuel efficiency.

In terms of the age of the generating units, almost 67 percent of the total coal generating capacity has been in service for more than 40 years, while nearly 81 percent of the natural gas capacity has been in service less than 40 years. Figure 2-3 presents the cumulative age distributions of the coal and gas fleets, highlighting the pronounced differences in the ages of the fleets of these two types of fossil-fuel generating capacity. Figure 2-3 also includes the distribution of generation, which is similar to the distribution of capacity.

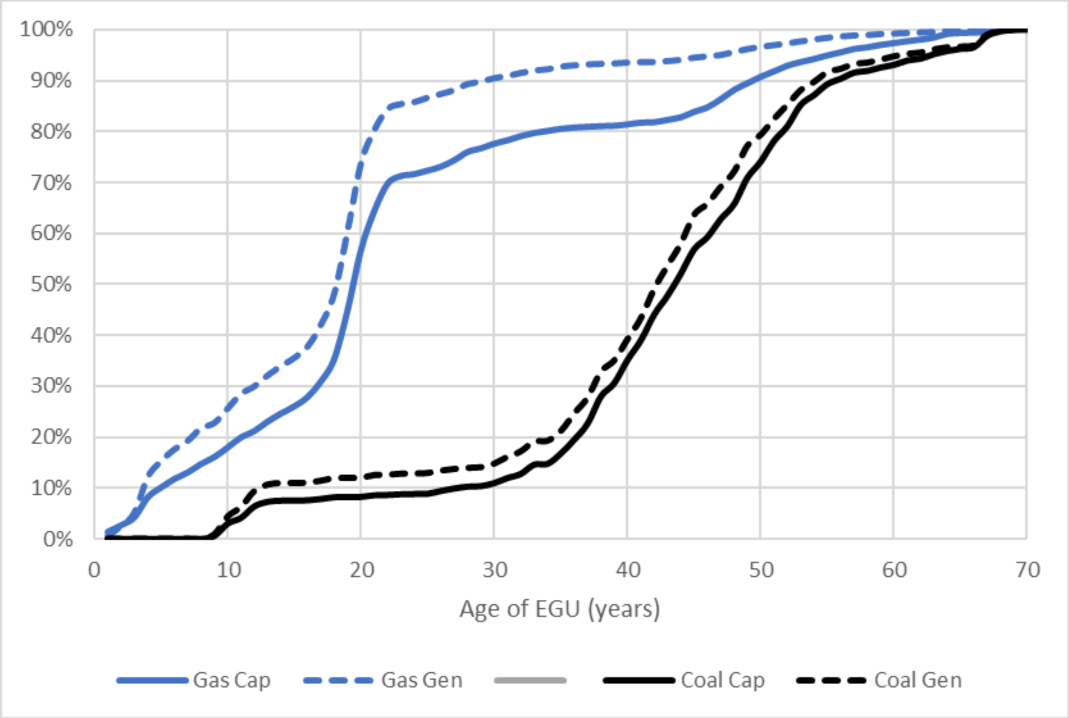

Figure 2-3 Cumulative Distribution in 2021 of Coal and Natural Gas Electricity Capacity and Generation, by Age

Source: eGRID 2021 (November 2023 release from EPA eGRID website). Figure presents data from generators that came online between 1950 and 2021 (inclusive); a 71-year period. Full eGRID data include generators that came online as far back as 1915. Full data from 1915 onward are used in calculating cumulative distributions; figure truncation at 70 years is merely to improve visibility of diagram.

The locations of existing fossil units in EPA's National Electric Energy Data System (NEEDS) v.6 are shown in Figure 2-4.

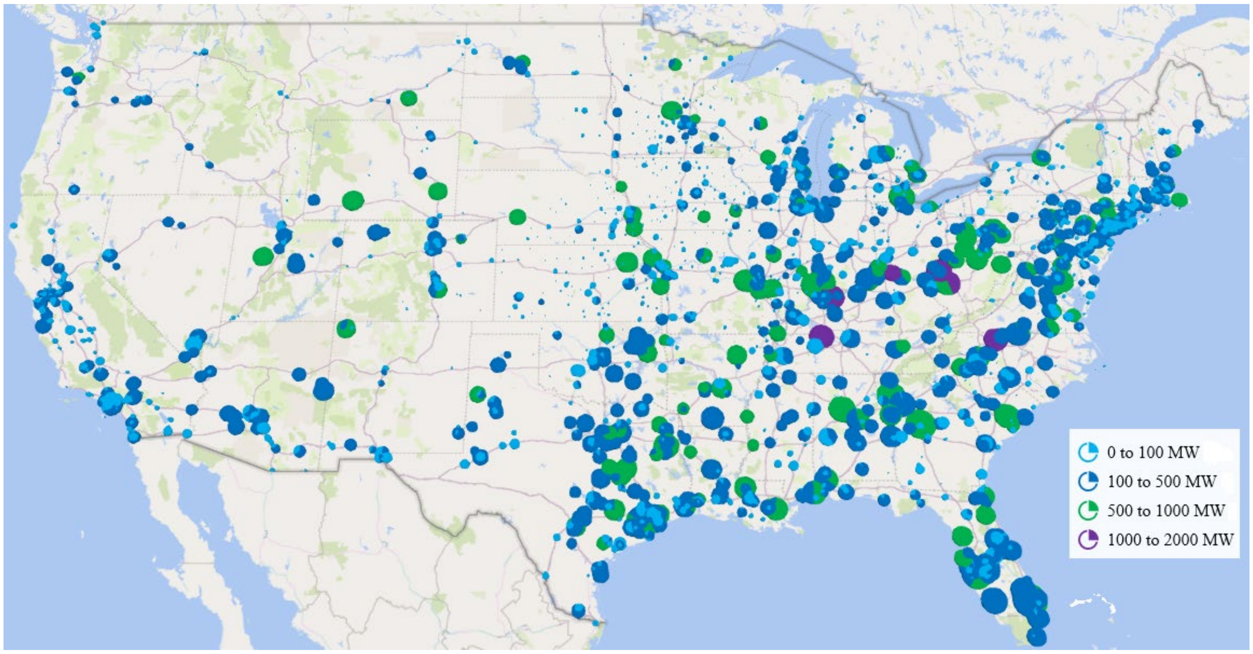

Figure 2-4 Fossil Fuel-Fired Electricity Generating Facilities, by Size
Source: National Electric Energy Data System (NEEDS) v.6
Note: This map displays fossil capacity at facilities in the NEEDS v.6 IPM frame. NEEDS v.6 reflects generating capacity expected to be on-line at the end of 2023. This includes planned new builds already under construction and planned retirements. In areas with a dense concentration of facilities, some facilities may be obscured.

The costs of renewable generation have fallen significantly due to technological advances, improvements in performance, and local, state, and federal incentives such as the recent extension of federal tax credits. According to Lazard, a financial advisory and asset management firm, the current unsubsidized levelized cost of electricity for wind and solar energy technologies is lower than the cost of technologies like coal, natural gas or nuclear, and in some cases even lower than just the operating cost, which is expected to lead to ongoing and significant deployment of renewable energy. Levelized cost of electricity is only one metric used to compare the cost of different generating technologies. It contains a number of uncertainties including utilization and regional factors.[23] While this chart illustrates general trends, unit specific build decisions will incorporate many other variables. These trends of declining costs

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[23] Lazard, Levelized Cost of Energy Analysis-Version 16.0, 2023. *https://www.lazard.com/media/typdgxmm/lazards-lcoeplus-april-2023.pdf.*

and cost projections for renewable resources are borne out by a range of other studies including the NREL Annual Technology Baseline,[24] DOE's Land-Based Wind Market Report,[25] LBNL's Utility Scale solar report,[26] EIA's Annual Energy Outlook,[27] and DOE's 2022 Grid Energy Storage Technology Cost and Performance Assessment.[28]

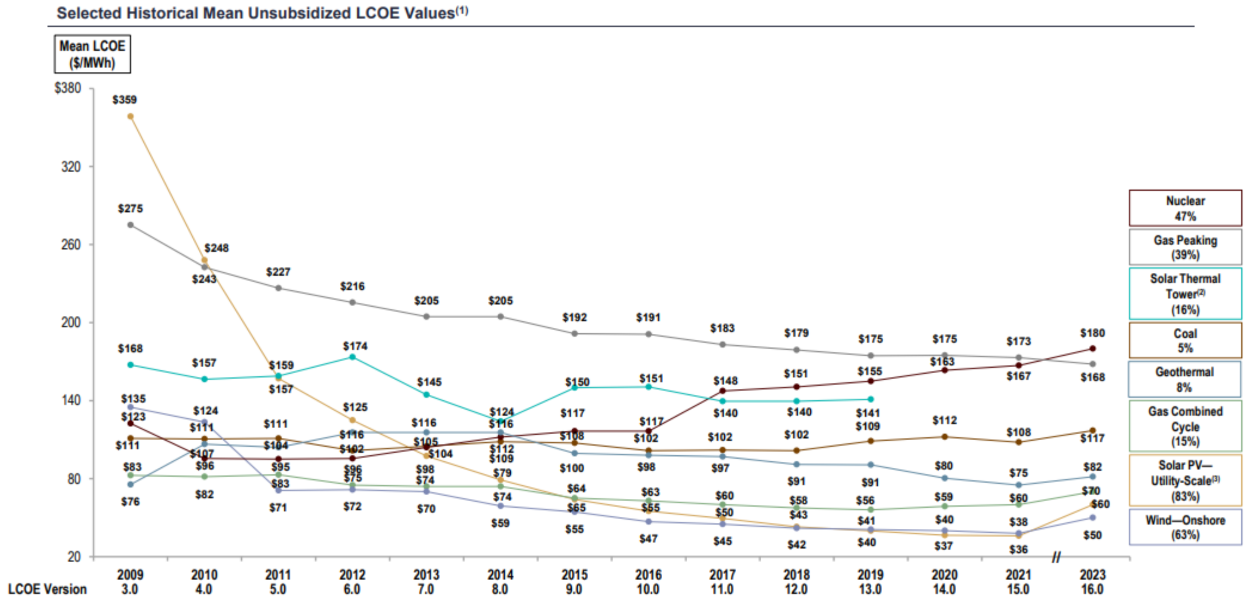

Figure 2-5 Selected Historical Mean LCOE Values
Source: Lazard, Levelized Cost of Energy Analysis-Version 16.0, April 2023

The broad trends away from coal-fired generation and toward lower-emitting generation are reflected in the recent actions and recently announced plans of many power plants across the industry — spanning all types of companies in all locations. Throughout the country, utilities have included commitments towards cleaner energy in public releases, planning documents, and integrated resource plans (IRPs). For strategic business reasons and driven by the economics of different supply options, most major utilities plan to increase their renewable energy holdings and continue reducing GHG emissions, regardless of what federal regulatory requirements might exist.

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[24] Available at: *https://atb.nrel.gov/*.
[25] Available at: *https://www.energy.gov/eere/wind/articles/land-based-wind-market-report-2022-edition*.
[26] Available at: *https://emp.lbl.gov/utility-scale-solar/*.
[27] Available at: *https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf*.
[28] Available at: *https://www.energy.gov/eere/analysis/2022-grid-energy-storage-technology-cost-and-performance-assessment*.

While EPA does not account for future planning statements from utility providers in the economic modeling since they are not legally enforceable, the number and scale of these announcements is significant on a systemic level. These statements are part of long-term planning processes that cannot be easily revoked due to considerable stakeholder involvement in the planning process, including the involvement of regulators. The direction to which these utility providers have publicly stated they are moving is consistent across the sector and undergirded by market fundamentals lending economic credibility to these commitments and confidence that that most plans will be implemented.

2.2.2 Transmission

Transmission is the term used to describe the bulk transfer of electricity over a network of high voltage lines, from electric generators to substations where power is stepped down for local distribution. In the U.S. and Canada, there are three separate interconnected networks of high voltage transmission lines,[29] each operating synchronously. Within each of these transmission networks, there are multiple areas where the operation of power plants is monitored and controlled by regional organizations to ensure that electricity generation and load are kept in balance. In some areas, the operation of the transmission system is under the control of a single regional operator;[30] in others, individual utilities[31] coordinate the operations of their generation, transmission, and distribution systems to balance the system across their respective service territories.

2.2.3 Distribution

Distribution of electricity involves networks of lower voltage lines and substations that take the higher voltage power from the transmission system and step it down to lower voltage levels to match the needs of customers. The transmission and distribution system is the classic example of a natural monopoly, in part because it is not practical to have more than one set of

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[29] These three network interconnections are the Western Interconnection, comprising the western parts of both the U.S. and Canada (approximately the area to the west of the Rocky Mountains), the Eastern Interconnection, comprising the eastern parts of both the U.S. and Canada (except those part of eastern Canada that are in the Quebec Interconnection), and the Texas Interconnection (which encompasses the portion of the Texas electricity system commonly known as the Electric Reliability Council of Texas (ERCOT)). See map of all NERC interconnections at *https://www.nerc.com/AboutNERC/keyplayers/PublishingImages/NERC%20Interconnections.pdf.*

[30] For example, PJM Interconnection, LLC.

[31] For example, Los Angeles Department of Water and Power, Florida Power and Light.

lines running from the electricity generating sources to substations or from substations to residences and businesses.

Over the last few decades, several jurisdictions in the U.S. began restructuring the power industry to separate transmission and distribution from generation, ownership, and operation. Historically, vertically integrated utilities established much of the existing transmission infrastructure. However, as parts of the country have restructured the industry, transmission infrastructure has also been developed by transmission utilities, electric cooperatives, and merchant transmission companies, among others. Distribution, also historically developed by vertically integrated utilities, is now often managed by a number of utilities that purchase and sell electricity, but do not generate it. Electricity restructuring has focused primarily on efforts to reorganize the industry to encourage competition in the generation segment of the industry, including ensuring open access of generation to the transmission and distribution services needed to deliver power to consumers. In many states, such efforts have also included separating generation assets from transmission and distribution assets to form distinct economic entities. Transmission and distribution remain price-regulated throughout the country based on the cost of service.

2.3 Sales, Expenses, and Prices

Electric generating sources provide electricity for ultimate commercial, industrial, and residential customers. Each of the three major ultimate categories consume roughly a quarter to a third of the total electricity produced (see Table 2-6).[32] Some of these uses are highly variable, such as heating and air conditioning in residential and commercial buildings, while others are relatively constant, such as industrial processes that operate 24 hours a day. The distribution between the end use categories changed very little between 2010 and 2022.

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[32] Transportation (primarily urban and regional electrical trains) is a fourth ultimate customer category which accounts less than one percent of electricity consumption.

Table 2-6 Total U.S. Electric Power Industry Retail Sales, 2010-22 and 2014-22 (billion kWh)

		2010		2022	
		Sales/Direct Use (Billion kWh)	**Share of Total End Use**	**Sales/Direct Use (Billion kWh)**	**Share of Total End Use**
Sales	Residential	1,446	37%	1,509	37%
	Commercial	1,330	34%	1,391	34%
	Industrial	971	25%	1,020	25%
	Transportation	8	0%	7	0%
Total		3,755	97%	3,927	97%
Direct Use			132		140
Total End Use			**3,887**		**4,067**
		2015		**2022**	
		Sales/Direct Use (Billion kWh)	**Share of Total End Use**	**Sales/Direct Use (Billion kWh)**	**Share of Total End Use**
Sales	Residential	1,404	36%	1,509	37%
	Commercial	1,361	35%	1,391	34%
	Industrial	987	25%	1,020	25%
	Transportation	8	0%	7	0%
Total		3,759	96%	3,927	97%
Direct Use			141		140
Total End Use			**3,900**		**4,067**

Source: Table 2.2, EIA Electric Power Annual, 2022 (October 19, 2023, release)
Notes: Retail sales are not equal to net generation (Table 2-2) because net generation includes net imported electricity and loss of electricity that occurs through transmission and distribution, along with data collection frame differences and non-sampling error. Direct Use represents commercial and industrial facility use of onsite net electricity generation; electricity sales or transfers to adjacent or co-located facilities; and barter transactions.

2.3.1 Electricity Prices

Electricity prices vary substantially across the U.S., differing both between the ultimate customer categories and by state and region of the country. Electricity prices are typically highest for residential and commercial customers because of the relatively high costs of distributing electricity to individual homes and commercial establishments. The higher prices for residential and commercial customers are the result of the extensive distribution network reaching to virtually every building in every part of the country and the fact that generating stations are increasingly located relatively far from population centers, increasing transmission costs. Industrial customers generally pay the lowest average prices, reflecting both their proximity to generating stations and the fact that industrial customers receive electricity at higher voltages (which makes transmission more efficient and less expensive). Industrial customers frequently pay variable prices for electricity, varying by the season and time of day, while residential and commercial prices have historically been less variable. Overall, industrial customer prices are usually considerably closer to the wholesale marginal cost of generating electricity than residential and commercial prices.

On a state-by-state basis, all retail electricity prices vary considerably. In 2022, the national average retail electricity price (all sectors) was 12.4 cents/kWh, with a range from 8.2 cents (Wyoming) to 39.72 cents (Hawaii).[33]

The real year prices for 2010 through 2022 are shown in Figure 2-6. Average national retail electricity prices decreased between 2010 and 2022 by 4 percent in real terms (2022 dollars), and 2 percent between 2015-22.[34] The amount of decrease differed for the three major end use categories (residential, commercial, and industrial). National average commercial prices decreased the most (4 percent), and industrial prices decreased the least (1 percent) between 2015-21.

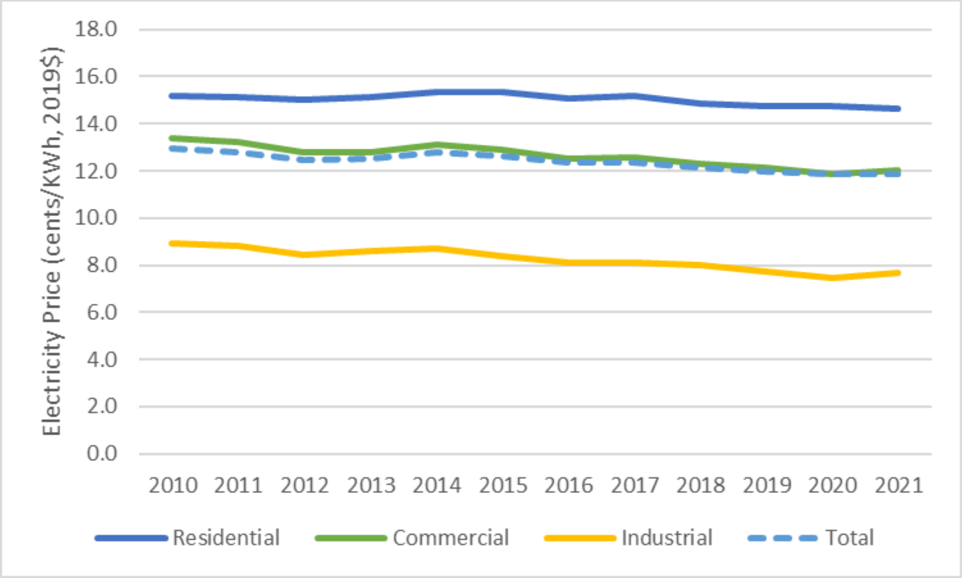

Figure 2-6 Real National Average Electricity Prices (including taxes) for Three Major End-Use Categories
Source: EIA. Electric Power Annual 2022 and 2021, Table 2.4.

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[33] EIA State Electricity Profiles with Data for 2022 (*http://www.eia.gov/electricity/state/*).
[34] All prices in this section are estimated as real 2022 prices adjusted using the GDP implicit price deflator unless otherwise indicated.

2.3.2 Prices of Fossil Fuel Used for Generating Electricity

Another important factor in the changes in electricity prices are the changes in delivered fuel prices[35] for the three major fossil fuels used in electricity generation: coal, natural gas, and petroleum products. Relative to real prices in 2015, the national average real price (in 2022 dollars) of coal delivered to EGUs in 2022 had decreased by 12 percent, while the real price of natural gas increased by 84 percent. The real price of delivered petroleum products also increased by 102 percent, and petroleum products declined as an EGU fuel (in 2022 petroleum products generated 1 percent of electricity). The combined real delivered price of all fossil fuels (weighted by heat input) in 2022 increased by 62 percent over 2015 prices. Figure 2-7 shows the relative changes in real price of all three fossil fuels between 2010 and 2022.

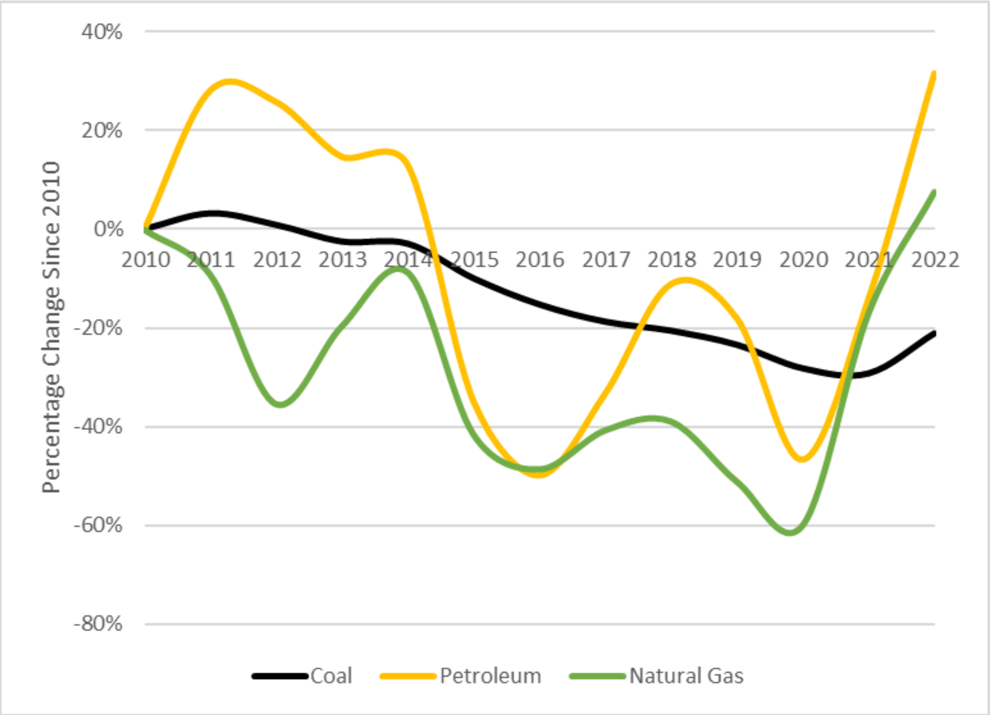

Figure 2-7 Relative Real Prices of Fossil Fuels for Electricity Generation; Change in National Average Real Price per MMBtu Delivered to EGU
Source: EIA. Electric Power Annual 2022, Table 7.1.

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[35] Fuel prices in this section are all presented in terms of price per MMBtu to make the prices comparable.

2.3.3 Changes in Electricity Intensity of the U.S. Economy from 2010 to 2021

An important aspect of the changes in electricity generation (i.e., electricity demand) between 2010 and 2022 is that while total net generation increased by 4 percent over that period, the demand growth for generation was lower than both the population growth (8 percent) and real GDP growth (30 percent). Figure 2-8 shows the growth of electricity generation, population, and real GDP during this period.

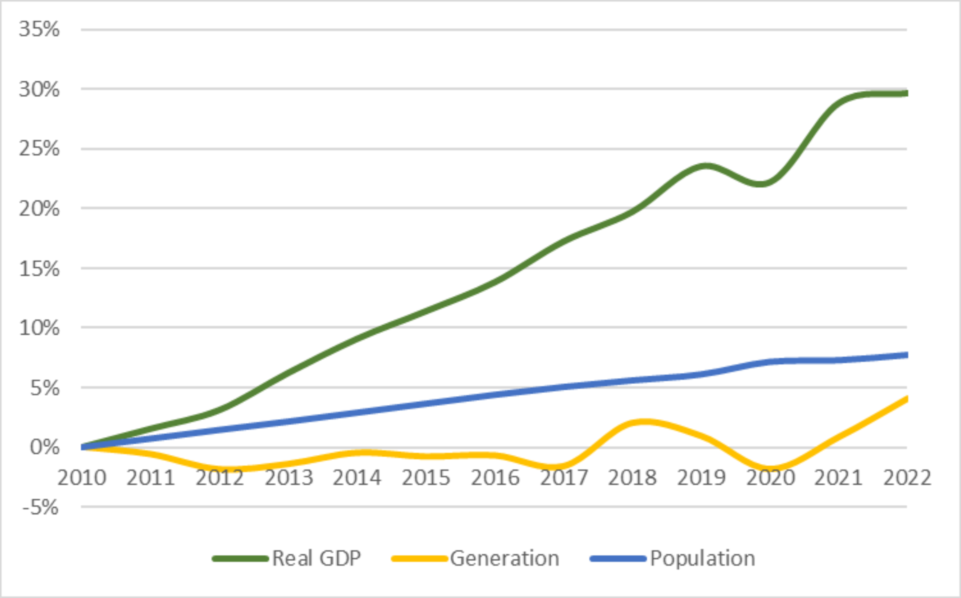

Figure 2-8 Relative Growth of Electricity Generation, Population and Real GDP Since 2010
Sources: Generation: U.S. EIA Electric Power Annual 2022. Population: U.S. Census. Real GDP: U.S. Bureau of Economic Analysis

Because demand for electricity generation grew more slowly than both the population and GDP, the relative electric intensity of the U.S. economy improved (i.e., less electricity used per person and per real dollar of output) during 2010 to 2022. On a per capita basis, real GDP per capita grew by 20 percent between 2010 and 2022. At the same time, electricity generation per capita decreased by 3 percent. The combined effect of these two changes improved the overall electricity generation efficiency in the U.S. market economy. Electricity generation per dollar of real GDP decreased 20 percent. These relative changes are shown in Figure 2-9.

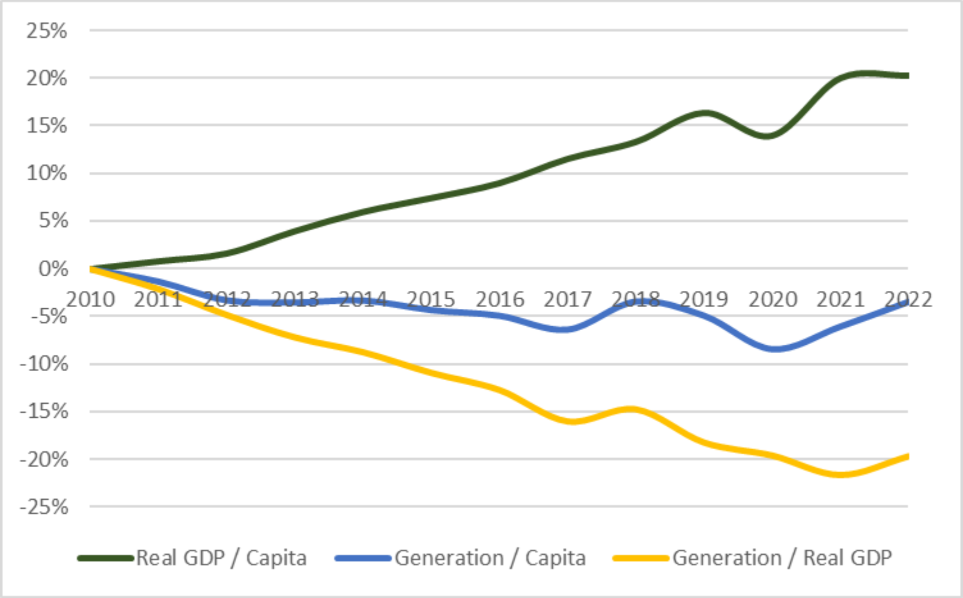

Figure 2-9 Relative Change of Real GDP, Population and Electricity Generation Intensity Since 2010

Sources: Generation: U.S. EIA Electric Power Annual 2021 and 2020. Population: U.S. Census. Real GDP: 2022 Economic Report of the President, Table B-3.

COSTS, EMISSIONS, AND ENERGY IMPACTS

3.1 Introduction

This section presents the compliance cost, emissions, and energy impact analysis performed for the MATS RTR. EPA used the Integrated Planning Model (IPM), developed by ICF Consulting, to conduct its analysis. IPM is a dynamic linear programming model that can be used to examine air pollution control policies for SO_2, NO_X, Hg, HCl, PM, and other air pollutants throughout the U.S. for the entire power system. Documentation for EPA's Power Sector Modeling Platform 2023 using IPM (hereafter IPM Documentation) can be found at *https://www.epa.gov/power-sector-modeling* and is available in the docket for this action.

3.2 EPA's Power Sector Modeling Platform 2023 using IPM

IPM is a state-of-the-art, peer-reviewed, dynamic linear programming model that can be used to project power sector behavior under future business-as-usual conditions and to examine prospective air pollution control policies throughout the contiguous U.S. for the entire electric power system. For this RIA, EPA used IPM to project likely future electricity market conditions with and without this rulemaking.

IPM, developed by ICF, is a multi-regional, dynamic, deterministic linear programming model of the contiguous U.S. electric power sector. It provides estimates of least cost capacity expansion, electricity dispatch, and emissions control strategies while meeting energy demand and environmental, transmission, dispatch, and reliability constraints. IPM's least-cost dispatch solution is designed to ensure generation resource adequacy, either by using existing resources or through the construction of new resources. IPM addresses reliable delivery of generation resources for the delivery of electricity between the 78 IPM regions, based on current and planned transmission capacity, by setting limits to the ability to transfer power between regions using the bulk power transmission system. Notably, the model includes cost and performance estimates for state-of-the-art air pollution control technologies with respect to Hg, fPM, and other HAP controls.

EPA has used IPM for almost three decades to better understand power sector behavior under future business-as-usual conditions and to evaluate the economic and emissions impacts of prospective environmental policies. The model is designed to reflect electricity markets as accurately as possible. EPA uses the best available information from utilities, industry experts, gas and coal market experts, financial institutions, and government statistics as the basis for the detailed power sector modeling in IPM. The model documentation provides additional information on the assumptions discussed here as well as all other model assumptions and inputs.[36]

The model incorporates a detailed representation of the fossil-fuel supply system that is used to estimate equilibrium fuel prices. The model uses natural gas fuel supply curves and regional gas delivery costs (basis differentials) to simulate the fuel price associated with a given level of gas consumption within the system. These inputs are derived using ICF's Gas Market Model (GMM), a supply/demand equilibrium model of the North American gas market.[37]

IPM also endogenously models the partial equilibrium of coal supply and EGU coal demand levels throughout the contiguous U.S., taking into account assumed non-power sector demand and imports/exports. IPM reflects 36 coal supply regions, 14 coal grades, and the coal transport network, which consists of over four thousand linkages representing rail, barge, and truck and conveyer linkages. The coal supply curves in IPM were developed during a thorough bottom-up, mine-by-mine approach that depicts the coal choices and associated supply costs that power plants would face if selecting that coal over the modeling time horizon. The IPM documentation outlines the methods and data used to quantify the economically recoverable coal reserves, characterize their cost, and build the 36 coal regions' supply curves.[38]

To estimate the annualized costs of additional capital investments in the power sector, EPA uses a conventional and widely accepted approach that applies a capital recovery factor (CRF) multiplier to capital investments and adds that to the annual incremental operating expenses. The CRF is derived from estimates of the power sector's cost of capital (i.e., private discount rate), the amount of insurance coverage required, local property taxes, and the life of capital.[39] It is important to note that there is no single CRF factor applied in the model; rather, the

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[36] Detailed information and documentation of EPA's Baseline run using EPA's Power Sector Modeling Platform 2023 using IPM, including all the underlying assumptions, data sources, and architecture parameters can be found on EPA's website at: *https://www.epa.gov/power-sector-modeling*.

[37] See Chapter 8 of EPA's IPM Documentation, available at: *https://www.epa.gov/power-sector-modeling*.

[38] See Chapter 7 EPA's IPM Documentation, available at: *https://www.epa.gov/power-sector-modeling*.

[39] See Chapter 10 of EPA's IPM Documentation, available at: *https://www.epa.gov/power-sector-modeling*.

CRF varies across technologies, book life of the capital investments, and regions in the model in order to better simulate power sector decision-making.

EPA has used IPM extensively over the past three decades to analyze options for reducing power sector emissions. Previously, the model has been used to estimate the costs, emission changes, and power sector impacts in the RIAs for the Clean Air Interstate Rule (U.S. EPA, 2005), the Cross-State Air Pollution Rule (U.S. EPA, 2011a), the Mercury and Air Toxics Standards (U.S. EPA, 2011b), the Clean Power Plan for Existing Power Plants (U.S. EPA, 2015b), the Cross-State Air Pollution Update Rule (U.S. EPA, 2016), the Repeal of the Clean Power Plan, and the Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units (U.S. EPA, 2019), the Revised Cross-State Air Pollution Update Rule (U.S. EPA, 2021), and the Good Neighbor Plan (2023b).

EPA has also used IPM to estimate the air pollution reductions and power sector impacts of water and waste regulations affecting EGUs, including contributing to RIAs for the Cooling Water Intakes (316(b)) Rule (U.S. EPA, 2014a), the Disposal of Coal Combustion Residuals from Electric Utilities rule (U.S. EPA, 2015c), the Steam Electric Effluent Limitation Guidelines (U.S. EPA, 2015a), and the Steam Electric Reconsideration Rule (U.S. EPA, 2020).

The model and EPA's input assumptions undergo periodic formal peer review. The rulemaking process also provides opportunity for expert review and comment by a variety of stakeholders, including owners and operators of capacity in the electricity sector that is represented by the model, public interest groups, and other developers of U.S. electricity sector models. The feedback that the Agency receives provides a highly detailed review of key input assumptions, model representation, and modeling results. IPM has received extensive review by energy and environmental modeling experts in a variety of contexts. For example, in September 2019, U.S. EPA commissioned a peer review[40] of EPA's v6 Reference Case using the Integrated Planning Model (IPM). Additionally, and in the late 1990s, the Science Advisory Board reviewed IPM as part of the CAA Amendments Section 812 prospective studies[41] that are periodically conducted. The Agency has also used the model in a number of comparative modeling exercises sponsored by Stanford University's Energy Modeling Forum over the past 20

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[40] See Response and Peer Review Report EPA Reference Case Version 6 Using IPM, available at: *https://www.epa.gov/power-sector-modeling/ipm-peer-reviews*.

[41] *http://www2.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act*.

years. IPM has also been employed by states (e.g., for the Regional Greenhouse Gas Initiative, the Western Regional Air Partnership, Ozone Transport Assessment Group), other Federal and state agencies, environmental groups, and industry.

3.3 Baseline

The modeled "baseline" for any regulatory impact analysis is a business-as-usual scenario that represents expected behavior in the electricity sector under market and regulatory conditions in the absence of a regulatory action. As such, the baseline run represents an element of the baseline for this RIA.[42] EPA frequently updates the baseline modeling to reflect the latest available electricity demand forecasts from the U.S. EIA as well as expected costs and availability of new and existing generating resources, fuels, emission control technologies, and regulatory requirements.

For our analysis of the MATS RTR rule, EPA used EPA's Power Sector Modeling Platform 2023 using IPM to provide power sector emissions projections for air quality modeling, as well as a companion updated database of EGU units (the National Electricity Energy Data System or NEEDS for IPM 2023[43]) that is used in EPA's modeling applications of IPM. The baseline for this final rule includes the Good Neighbor Plan (Final GNP), the Revised CSAPR Update, CSAPR Update, and CSAPR, as well as MATS. The baseline run also includes the 2015 Effluent Limitation Guidelines (ELG) and the 2015 Coal Combustion Residuals (CCR), and the recently finalized 2020 ELG and CCR rules.[44]

This version of the model, which is used as the baseline for this RIA, also includes recent updates to state and federal legislation affecting the power sector, including Public Law 117-169, 136 Stat. 1818 (August 16, 2022), commonly known as the Inflation Reduction Act of 2022 (the IRA). The IPM Documentation includes a summary of all legislation reflected in this version of the model as well as a description of how that legislation is implemented in the model.

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[42] As described in Chapter 5 of EPA's *Guidelines for Preparing Economic Analyses*, the baseline "should incorporate assumptions about exogenous changes in the economy that may affect relevant benefits and costs (e.g., changes in demographics, economic activity, consumer preferences, and technology), industry compliance rates, other regulations promulgated by EPA or other government entities, and behavioral responses to the proposed rule by firms and the public." (U.S. EPA, 2014b).

[43] *https://www.epa.gov/power-sector-modeling/national-electric-energy-data-system-needs*.

[44] For a full list of modeled policy parameters, please see: *https://www.epa.gov/power-sector-modeling*.

Under the baseline, the impacts of the IRA result in an acceleration of the ongoing shift towards lower emitting generation and declining generation share for fossil-fuel fired generation. A range of studies have outlined how reliability continues to be maintained under high variable renewable penetration scenarios. U.S. EPA (2023a) summarized results from fourteen multi-sector and power sector models under the IRA in 2030 and 2035. Across the models, wind and solar resources provide 22 to 54 percent of generation (with median of 45 percent) in 2030 and 21 to 80 percent (with median of 50 percent) in 2035. The North American Renewable Integration Study (Brinkman et al., 2021) showed how the U.S. could accommodate between 70 to 79 percent of wind and solar generation by 2050. The Solar Futures Study (DOE, 2021) illustrated power systems with upwards of 80 percent of renewable energy by 2050. Finally, Cole et al. (2021) demonstrates a 100 percent renewable power system for the contiguous U.S.

The inclusion of the final GNP and other regulatory actions (including federal, state, and local actions) in the base case is necessary in order to reflect the level of controls that are likely to be in place in response to other requirements apart from the scenarios analyzed in this section. This base case will provide meaningful projections of how the power sector will respond to the cumulative regulatory requirements for air emissions in totality, while isolating the incremental impacts of MATS RTR relative to a base case with other air emission reduction requirements separate from this final action.

The analysis of power sector cost and impacts presented in this section is based on a single policy run compared to the baseline run. The difference between the two runs represents the incremental impacts projected solely as a result of compliance with the final MATS RTR.

3.4 Regulatory Options Analyzed

For this RIA, EPA analyzed the regulatory options summarized in the table below, which are described in more detail in Section 1.3.1. The remainder of this section discusses the approach used for estimating the costs and/or emissions impacts of each provision of this final rule.

Table 3-1 Summary of Final Regulatory Options Examined in this RIA

Provision	Regulatory Options Examined in this RIA: Less Stringent	Regulatory Options Examined in this RIA: Final Rule
FPM Standard (Surrogate Standard for Non-Hg HAP Metals)	Retain existing fPM standard of 0.030 lb/MMBtu	Revised fPM standard of 0.010 lb/MMBtu
Hg Standard	Retain Hg standard for lignite-fired EGUs of 4.0 lb/TBtu	Revised Hg standard for lignite-fired EGUs of 1.2 lb/TBtu
Continuous Emissions Monitoring Systems (PM CEMS)	Require installation of PM CEMS to demonstrate compliance	Require installation of PM CEMS to demonstrate compliance
Startup Definition	Remove startup definition #2	Remove startup definition #2

As explained in Section 1.3.1, both the final rule and less stringent options described in Table 3-1 have not been changed from the proposed and less stringent options examined in the RIA for the proposal of this action. The proposal RIA included a more stringent regulatory option that projected the impacts of lowering the fPM standard to 0.006 lb/MMBtu, while holding the other three proposed amendments unchanged from the proposed option. EPA solicited comment on this more stringent fPM standard in the preamble of the proposed rule. As explained in section V.A.4. of the preamble of the final rule, EPA determined not to pursue a more stringent standard for fPM emissions, such as a limit of 0.006 lb/MMBtu. After considering comments to the proposed rule and after conducting additional analysis, EPA determined that a lower fPM standard would not be compatible with PM CEMS due to measurement uncertainty. As a result, this RIA does not examine a more stringent option than the suite of requirements that constitute the final rule; the final rule represents the most stringent suite of regulatory options available under the technology review.

The revisions to the fPM standard and the Hg standard are modeled endogenously within IPM. For the fPM standard, emissions controls and associated costs are modeled based on information available in the memorandum titled “2024 Update to the 2023 Proposed Technology Review for the Coal- and Oil-Fired EGU Source Category,” which is available in the docket. This memorandum summarizes the fPM emissions rate for each existing EGU. Based on the emissions rates detailed in this memorandum, EPA assumed various levels of O&M, ESP upgrades, upgrades to existing fabric filters, or new fabric filter installations to comply with each of the finalized standards in the modeling. Those assumptions are detailed in Table 3-2.

Table 3-2 PM Control Technology Modeling Assumptions[a]

PM Control Strategy	Cost (in 2019 dollars)	fPM Reduction
Operation & Maintenance (O&M)	$100,000/year	Unit-specific
Minor ESP Upgrades	$20/kW	20%
Typical ESP Upgrades	$40/kW	40%
ESP Rebuild	$80/kW	55% (0.005lb/MMBtu floor)
Upgrade Existing FF Bags	Unit-specific, approximately $15K - $500K annual O&M	50% (0.002 lb/MMBtu floor)
New Fabric Filter (6.0 A/C Ratio)	Unit-specific, $150-360/kW*	90% (0.002 lb/MMBtu floor)

[a] Capital costs are expressed here in terms of $/kW. O&M costs are expressed here on an annual basis.
* *https://www.epa.gov/system/files/documents/2021-09/attachment_5-7_pm_control_cost_development_methodology.pdf*

The cost and reductions associated with control of Hg emissions at lignite-fired EGUs are also modeled endogenously and reflect the assumption that each of these EGUs replace standard powdered activated carbon (PAC) sorbent with halogenated PAC sorbent.

While more detail on the costs associated with the PM CEMS requirement and the change in the startup definition is presented in Section 3.5.2, we note here that these costs were estimated exogenously without the use of the model that provides the bulk of the cost analysis for this RIA. As a result, the results of the power sector modeling do not include costs associated with these provisions, but the costs associated with requiring PM CEMS and the change in the startup definition are included in the total cost projections for the rule for each of the regulatory options analyzed in this RIA. As the incremental costs of requiring PM CEMS are small relative to the ongoing costs of operations, we do not think the endogenous incorporation of these costs would change any projected results in a meaningful way.

3.5 Power Sector Impacts

3.5.1 Emissions

As indicated previously, this RIA presents emissions reductions estimates in years 2028, 2030, and 2035 based on IPM projections.[45] Table 3-3 presents the estimated impact on power sector emissions resulting from compliance with the final rule in the contiguous U.S. The quantified emission estimates presented in the RIA include changes in pollutants directly covered by this rule, such as Hg and non-Hg HAP metals, and changes in other pollutants emitted from the power sector as a result of the compliance actions projected under this final rule. The model projections capture the emissions changes associated with implementation of HAP mitigation measures at affected sources as well as the resulting effects on dispatch as the relative operating costs for some affected units have changed. The projections indicate that the final rule results in reductions in emissions of Hg in all run years, of 16 percent, 17 percent, and 18 percent in 2028, 2030, and 2035, respectively, as well as reductions in $PM_{2.5}$ and PM_{10} emissions in all run years.

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[45] Note that baseline mercury emissions projections are higher than proposal due to a revision in final baseline modeling to better reflect current ACI performance at existing lignite-fired units.

Table 3-3 EGU Emissions and Projected Emissions Changes for the Baseline and the Final Rule for 2028, 2030, and 2035[a]

	Year	Total Emissions		Change from Baseline	% Change under Final Rule
		Baseline	Final Rule		
Hg (lbs.)	2028	6,129	5,129	-999.1	-16.3%
	2030	5,863	4,850	-1,013	-17.3%
	2035	4,962	4,055	-907.0	-18.3%
$PM_{2.5}$ (thousand tons)	2028	70.5	69.7	-0.77	-1.09%
	2030	66.3	65.8	-0.53	-0.79%
	2035	50.7	50.2	-0.47	-0.93%
PM_{10} (thousand tons)	2028	79.5	77.4	-2.07	-2.60%
	2030	74.5	73.1	-1.33	-1.79%
	2035	56.0	54.8	-1.18	-2.11%
SO_2 (thousand tons)	2028	454.3	454.0	-0.290	-0.06%
	2030	333.5	333.5	0.025	0.01%
	2035	239.9	239.9	-0.040	-0.02%
Ozone-season NO_X (thousand tons)	2028	189.0	188.8	-0.165	-0.09%
	2030	174.99	175.4	0.488	0.28%
	2035	116.99	119.1	2.282282	1.95%
Annual NO_X (thousand tons)	2028	460.55	460.3	-0.283	-0.06%
	2030	392.88	392.7	-0.022	-0.01%
	2035	253.44	253.5	0.066	0.03%
HCl (thousand tons)	2028	2.474	2.474	0.000	0.01%
	2030	2.184	2.184	0.000	0.01%
	2035	1.484	1.485	0.001	0.06%
CO_2 (million metric tons)	2028	1,158.8	1,158.7	-0.0655	-0.01%
	2030	1,098.3	1,098.3	0.0361	0.00%
	2035	724.2	724.1	-0.099	-0.01%

[a] This analysis is limited to the geographically contiguous lower 48 states. Values are independently rounded and may not sum.

We also estimate that the final rule will reduce at least seven tons of non-Hg HAP metals in 2028, five tons of non-Hg HAP metals in 2030, and four tons of non-Hg HAP metals in 2035. These reductions are composed of reductions in emissions of antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, nickel, and selenium.[46] Table 3-4 summarizes the total emissions reductions projected over the 2028 to 2037 analysis period.

Table 3-4 Cumulative Projected Emissions Reductions for the Final Rule, 2028 to 2037[a,b]

Pollutant	Emissions Reductions
Hg (pounds)	9,500
$PM_{2.5}$ (tons)	5,400
CO_2 (thousand tons)	650
SO_2 (tons)	770
NO_x (tons)	220
Non-Hg HAP metals (tons)	49

[a] Values rounded to two significant figures.
[b] Estimated reductions from model year 2028 are applied to 2028 and 2029, those from model year 2030 are applied to 2031 and 2032, and those from model year 2035 are applied to 2032 through 2037. These values are summed to generate total reduction figures.

Importantly, the continuous monitoring of fPM required in this rule will likely induce additional emissions reductions that we are unable to quantify. Continuous measurements of emissions accounts for changes to processes and fuels, fluctuations in load, operations of pollution controls, and equipment malfunctions. By measuring emissions across all operations, power plant operators and regulators can use the data to ensure controls are operating properly and to assess continuous compliance with relevant standards. Because CEMS enable power plant operators to quickly identify and correct problems with pollution control devices, it is possible that fPM emissions could be lower than they otherwise would have been for up to three months—or up to three years if testing less frequently under the LEE program— at a time. This potential reduction in fPM and non-Hg HAP metals emission resulting from the information provided by continuous monitoring coupled with corrective actions by plant operators could be sizeable over the existing coal-fired fleet and is not quantified in this rulemaking.

As we are finalizing the removal of paragraph (2) of the definition of "startup," the time period for engaging fPM or non-Hg HAP metal controls after non-clean fuel use, as well as for full operation of fPM or non-Hg HAP metal controls, is expected to be reduced when

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[46] The estimates on non-mercury HAP metals reductions were obtained my multiplying the ratio of non-mercury HAP metals to fPM by estimates of PM_{10} reductions under the rule, as we do not have estimates of fPM reductions using IPM, only PM_{10}. The ratios of non-mercury HAP metals to fPM were based on analysis of 2010 MATS Information Collection Request (ICR) data. As there may be substantially more fPM than PM_{10} reduced by the control techniques projected to be used under this rule, these estimates of non-mercury HAP metals reductions are likely underestimates. More detail on the estimated reduction in non-mercury HAP metals can be found in the docketed memorandum *Estimating Non-Hg HAP Metals Reductions for the 2024 Technology Review for the Coal-Fired EGU Source Category.*

transitioning to paragraph (1). The reduced time period for engaging controls therefore increases the duration in which pollution controls are employed and lowers emissions.

To the extent that the CEMS requirement and removal of the second definition of startup leads to actions that may otherwise not occur absent the amendments to those provisions in this final rule, there may be emissions impacts we are unable to estimate.

3.5.2 Compliance Costs

3.5.2.1 Power Sector Costs

The power industry's "compliance costs" are represented in this analysis as the change in electric power generation costs between the baseline and policy scenarios and are presented in Table 3-5. In other words, these costs are an estimate of the increased power industry expenditures required to implement the final rule requirements. The total compliance costs, presented in Section 3.5.2.4, are estimated for this RIA as the sum of two components. The first component, estimated using the modeling discussed above, is presented below in Table 3-5. This component constitutes the majority of the incremental costs for the final. The second component, the costs of the final rule PM CEMS requirement, is discussed in Section 3.5.2.2.

EPA projects that the annual incremental compliance cost of the final rule is $110 million, $110 million, and $93 million (2019 dollars) in 2028, 2030, and 2035, respectively. The annual incremental cost is the projected additional cost of complying with the final rule in the year analyzed and includes the amortized cost of capital investment and any applicable costs of operating additional pollution controls, investments in new generating sources, shifts between or amongst various fuels, and other actions associated with compliance. This projected cost does not include the compliance calculated outside of IPM modeling, namely the compliance costs related to PM CEMS. See Section 3.5.2.2 for further details on these costs. EPA believes that the cost assumptions used for this RIA reflect, as closely as possible, the best information available to the Agency today. See Section 3.5.4 for a discussion of projected capacity changes and Section 3.6 for a discussion of the uncertainty regarding necessary pollution controls.

Table 3-5 Power Sector Annualized Compliance Cost Estimates under the Final Rule in 2028, 2030, and 2035 (millions of 2019 dollars)

Analysis Year	Final Rule
2028	110
2030	110
2035	93

Note: Values have been rounded to two significant figures. As explained in Section 3.4, the incremental costs of requiring PM CEMS are small relative to the ongoing costs of operation, so the less stringent regulatory alternative in this RIA was not modeled using IPM. As a result, power sector impacts are not estimated for the less stringent regulatory option, but the costs associated with requiring PM CEMS (Table 3-6) are included in the total cost across regulatory options (Table 3-7).

3.5.2.2 PM CEMS Costs

In addition to revising the PM emission standard for existing coal-fired EGUs, EPA is revising the requirements for demonstrating compliance with the PM emission standard for coal- and oil-fired EGUs. The final PM standard renders the current limit for the LEE program moot since it is lower than the current PM LEE limit. Therefore, EPA is removing PM from the LEE program. Currently, EGUs that are not LEE units can demonstrate compliance with the fPM standard either by conducting performance testing quarterly, use of PM continuous parameter monitoring systems (CPMS) or using PM CEMS.

After considering updated information on the costs for performance testing compared to the cost of PM CEMS and capabilities of PM CEMS measurement abilities, as well as the benefits of using PM CEMS, which include increased transparency, compliance assurance, and accelerated identification of anomalous emissions, EPA is finalizing the requirement that all coal-fired EGUs and oil-fired EGUs demonstrate compliance with the PM emission standard by using PM CEMS.

The revision of PM limits alters the composition and duration of testing runs in facilities that use either compliance testing methodology. Estimated costs for quarterly fPM testing and PM CEMS are provided in the "Revised Estimated Non-Beta Gauge PM CEMS and Filterable PM Testing Costs" memorandum, available in the docket. The annualized costs for units currently employing EPA Method 5 quarterly testing are estimated at about $60,000.[47] EPA calibrated its cost estimates for PM CEMS in response to observed installations, manufacturer input, public comment, and engineering analyses. These calibrations include an assumed

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[47] EGUs receiving contractual or quantity discounts from performance test provides may incur lower costs.

replacement lifespan of 15 years and an interest rate of 7 percent to approximate the prevailing bank prime rate. For the portion of EGUs that employ PM CEMS, we estimate the annualized costs to be about $72,000.

To produce an inventory of total units which would require the installation of PM CEMS under the final rule as well as the incremental costs of the requirement, EPA began with an inventory of all existing coal-fired EGUs with capacity great enough to be regulated by MATS. That inventory was then filtered to remove EGUs with planned retirements or coal to gas conversions prior to 2028 from analysis of both the baseline and final rule. Within that remaining inventory of 314 EGUs, we used recent compliance data to determine that 120 units have installed PM CEMS, while 177 units use quarterly testing and do not have existing PM CEMS installations. The remaining 17 units (for which fPM compliance data were not available) are assumed to use quarterly testing and not have existing PM CEMS installations.

Table 3-6 Incremental Cost of Final Continuous Emissions Monitoring (PM CEMS) Requirement

Compliance Approach in Baseline	Units (no.)	Baseline Cost (per year per unit)	Total Baseline Costs (per year)	Final Rule (per year per unit)	Final Rule Costs (per year)	Incremental Costs (per year)
Quarterly Testing	190	$60,000	$12,000,000	$72,000	$14,000,000	$2,300,000
PM CEMS	120	$72,000	$8,700,000	$72,000	$8,700,000	$0
Total	**320**	**---**	**$20,000,000**	**---**	**$23,000,000**	**$2,300,000**

Note: Values rounded to two significant figures. Rows may not appear to add correctly due to rounding.

As detailed in Table 3-6, relative to the baseline scenario, revised PM CEMS cost estimates in the final rule leads to an estimated incremental cost of about $12,000 per year per unit for EGUs currently employing quarterly testing. The final rule results in costs of about $2.3 million per year in total.

3.5.2.3 Startup Definition Costs

EPA is finalizing the removal of one of the two options for defining the startup period for EGUs. The first option defines startup as either the first-ever firing of fuel in a boiler for the purpose of producing electricity, or the firing of fuel in a boiler after a shutdown event for any purpose. Startup ends when any of the steam from the boiler is used to generate electricity for sale over the grid or for any other purpose (including on-site use). In the second option, startup is defined as the period in which operation of an EGU is initiated for any purpose. Startup begins with either the firing of any fuel in an EGU for the purpose of producing electricity or useful thermal energy (such as heat or steam) for industrial, commercial, heating, or cooling purposes (other than the first-ever firing of fuel in a boiler following construction of the boiler) or for any other purpose after a shutdown event. Startup ends four hours after the EGU generates electricity that is sold or used for any other purpose (including on-site use), or four hours after the EGU makes useful thermal energy (such as heat or steam) for industrial, commercial, heating, or cooling purposes, whichever is earlier. This second option, referred to as paragraph (2) of the definition of "startup," required clean fuel use to the maximum extent possible, operation of PM control devices within one hour of introduction of primary fuel (*i.e.*, coal, residual oil, or solid oil-derived fuel) to the EGU, collection and submission of records of clean fuel use and emissions control device capabilities and operation, as well as adherence to applicable numerical standards within four hours of the generation of electricity or thermal energy for use either on site or for sale over the grid (*i.e.*, the end of startup) and to continue to maximize clean fuel use throughout that period.

According to EPA analysis, owners or operators of coal- and oil-fired EGUs that generated over 98 percent of electricity in 2022 have made the requisite adjustments, whether through greater clean fuel capacity, better tuned equipment, better trained staff, a more efficient and/or better design structure, or a combination of factors, to be able to meet the requirements of paragraph (1) of the startup definition. This ability points out an improvement in operation that all EGUs should be able to meet at little to no additional expenditure since the additional recordkeeping and reporting provisions associated with the work practice standards of paragraph (2) of the startup definition were more expensive than the requirements of paragraph (1) of the definition. As a result, this RIA does not incorporate any additional costs of this finalized provision.

3.5.2.4 Total Compliance Costs

The estimates of the total compliance costs are presented in Table 3-7. The total costs are composed of the change in electric power generation costs between the baseline and policy scenarios as presented in Table 3-5 and the incremental cost of the final PM CEMS requirement as detailed in Table 3-6. There are no anticipated costs associated with this rule prior to 2028.

Table 3-7 Stream of Projected Compliance Costs for the Final Rule and Less Stringent Regulatory Alternative (millions of 2019 dollars)[a]

	Regulatory Alternative	
Year	**Final Rule[b]**	**Less Stringent**
2028 (applied to 2028 and 2029)[b]	110	2.3
2030 (applied to 2030 and 2031)[b]	120	2.3
2035 (applied to 2032 to 2037)[b]	95	2.3
2% Discount Rate		
PV	**860**	**19**
EAV	**96**	**2.3**
3% Discount Rate		
PV	**790**	**18**
EAV	**92**	**2.1**
7% Discount Rate		
PV	**560**	**13**
EAV	**80**	**1.8**

[a] Values rounded to two significant figures. PV and EAV discounted to 2023.

[b] IPM run years apply to particular calendar years as reported in the table. The run year information as applied to individual calendar years is thus used to calculate PV and EAVs. Values rounded to two significant figures.

3.5.3 Projected Compliance Actions for Emissions Reductions

Electric generating units subject to the Hg and fPM emission limits in this final rule will likely use various Hg and PM control strategies to comply. This section summarizes the projected compliance actions related to each of these emissions limits.

The 2028 baseline includes approximately 5 GW of operational minemouth EGU capacity designed to burn low rank virgin coal. All of this capacity is currently equipped with Activated Carbon Injection (ACI) technology, and operation of this technology is reflected in the baseline. Each of these EGUs projected to consume lignite is assigned an additional variable operating cost that is consistent with achieving a 1.2 lb/MMBtu limit. Under the final rule, this additional cost does not result in incremental retirements for these units, nor does it result in a significant change to the projected generation level for these units.

The baseline also includes 11.6 GW of operational coal capacity that, based on the analysis documented in the EPA docketed memorandum titled “2024 Update to the 2023 Proposed Technology Review for the Coal- and Oil-Fired EGU Source Category,” EPA assumes would either need to improve existing PM controls or install new PM controls to comply with the final rule in 2028. The various PM control upgrades that EPA assumes would be necessary to achieve the emissions limits analyzed are summarized in Table 3-8.

Table 3-8 Projected PM Control Strategies under the Final Rule in 2028 (GW)

PM Control Strategy	Projected Actions and Retrofits under the Final Rule
Additional O&M	3.7
Minor ESP Upgrades	0.7
Typical ESP Upgrades	2.0
ESP Rebuild	2.4
FF Bag Upgrade	1.3
New Fabric Filter	1.5
Total	**11.6**

Except for one facility (Colstrip, located in Montana), all of the 11.6 GW of operational coal capacity that EPA assumes would need to take some compliance action to meet the final standards are currently operating existing ESPs and/or fabric filters. All of that capacity is projected to install the controls summarized in Table 3-8 and remain operational in 2028.

3.5.4 Generating Capacity

In this section, we discuss the projected changes in capacity by fuel type, building on and adding greater context to the information presented in the previous section. We first look at total capacity by fuel type, then retirements by fuel type, and finally new capacity builds by fuel type for the 2028, 2030, and 2035 run years.

Table 3-9 shows the total net projected capacity by fuel type for the baseline and the final rule for 2028, 2030, and 2035. Here, we see the net effects of projected retirements (Table 3-10) and new capacity builds (see Table 3-11). There are no significant incremental changes in capacity projected in response to the final rule for any given fuel type.

Table 3-9 2028, 2030, and 2035 Projected U.S. Capacity by Fuel Type for the Baseline and the Final Rule

	Total Generation Capacity (GW)			
	Baseline	Final Rule	Change under Final Rule	
			GW	%
2028				
Coal	105.8	105.8	0.0	0.0%
Natural Gas	471.0	471.0	0.0	0.0%
Oil/Gas Steam	62.6	62.6	0.0	0.0%
Non-Hydro RE	394.1	394.1	0.0	0.0%
Hydro	102.4	102.4	0.0	0.0%
Energy Storage	46.7	46.7	0.0	0.0%
Nuclear	93.6	93.6	0.0	0.0%
Other	6.5	6.5	0.0	0.0%
Total	**1,282.7**	**1,282.7**	**0.0**	**0.0%**
2030				
Coal	85.0	85.0	0.0	0.0%
Natural Gas	478.6	478.6	0.0	0.0%
Oil/Gas Steam	64.3	64.3	0.0	0.0%
Non-Hydro RE	440.2	440.2	0.0	0.0%
Hydro	103.7	103.7	0.0	0.0%
Energy Storage	58.6	58.6	0.0	0.0%
Nuclear	90.9	90.9	0.0	0.0%
Other	6.5	6.5	0.0	0.0%
Total	**1,327.7**	**1,327.7**	**0.0**	**0.0%**
2035				
Coal	51.6	51.6	0.0	0.0%
Natural Gas	476.0	476.0	0.0	0.0%
Oil/Gas Steam	55.3	55.3	0.0	0.0%
Non-Hydro RE	698.5	698.5	0.0	0.0%
Hydro	107.3	107.3	0.0	0.0%
Energy Storage	113.6	113.6	0.0	0.0%
Nuclear	83.7	83.7	0.0	0.0%
Other	6.5	6.5	0.0	0.0%
Total	**1,592.4**	**1,592.4**	**0.0**	**0.0%**

Note: In this table, “Non-Hydro RE” includes biomass, geothermal, landfill gas, solar, and wind.

Table 3-10 shows the total capacity projected to retire by fuel type for the baseline and the final rule in all run years. The final rule is not projected to result in changes to projected retirements.

Table 3-10 2028, 2030, and 2035 Projected U.S. Retirements by Fuel Type for the Baseline and the Final Rule

	Projected Retirements (GW)		
	Baseline	**Final Rule**	**% Change under Final Rule**
	2028		
Coal	37.8	37.8	0.0%
Natural Gas	1.3	1.3	0.0%
Oil/Gas Steam	12.4	12.4	0.0%
Non-Hydro RE	2.9	2.9	0.0%
Hydro	0.1	0.1	0.0%
Nuclear	0.0	0.0	0.0%
Other	0.0	0.0	0.0%
Total	**54.4**	**54.4**	**0.0%**
	2030		
Coal	56.7	56.6	0.0%
Natural Gas	1.7	1.7	0.0%
Oil/Gas Steam	12.4	12.4	0.0%
Non-Hydro RE	2.9	2.9	0.0%
Hydro	0.1	0.1	0.0%
Nuclear	2.7	2.7	0.0%
Other	0.0	0.0	0.0%
Total	**76.5**	**76.5**	**0.0%**
	2035		
Coal	83.7	83.7	0.0%
Natural Gas	4.3	4.3	0.0%
Oil/Gas Steam	22.7	22.7	0.0%
Non-Hydro RE	3.0	3.0	0.0%
Hydro	0.1	0.1	0.0%
Nuclear	9.9	9.9	0.0%
Other	0.1	0.1	0.0%
Total	**123.7**	**123.7**	**0.0%**

Note: In this table, “Non-Hydro RE” includes biomass, geothermal, landfill gas, solar, and wind.

Finally, Table 3-11 shows the projected U.S. new capacity builds by fuel type for the baseline and the final rule in all run years. For the final rule, the incremental changes in projected new capacity for any given fuel type are negligible.

Table 3-11 2028, 2030, and 2035 Projected U.S. New Capacity Builds by Fuel Type for the Baseline and the Final Rule

	New Capacity (GW)		
	Baseline	**Final Rule**	**% Change under Final Rule**
	2028		
Coal	0.0	0.0	0.0%
Natural Gas	26.2	26.2	0.0%
Energy Storage	3.2	3.2	0.2%
Non-Hydro RE	44.8	44.8	0.0%
Hydro	0.0	0.0	0.0%
Nuclear	0.0	0.0	0.0%
Other	0.0	0.0	0.0%
Total	**74.3**	**74.3**	**0.0%**
	2030		
Coal	0.0	0.0	0.0%
Natural Gas	34.3	34.3	0.0%
Energy Storage	15.2	15.2	0.0%
Non-Hydro RE	90.8	90.8	0.0%
Hydro	1.3	1.3	0.0%
Nuclear	0.0	0.0	0.0%
Other	0.0	0.0	0.0%
Total	**141.5**	**141.6**	**0.0%**
	2035		
Coal	0.0	0.0	0.0%
Natural Gas	34.2	34.2	0.0%
Energy Storage	70.2	70.2	0.1%
Non-Hydro RE	349.4	349.4	0.0%
Hydro	4.9	4.9	0.0%
Nuclear	0.0	0.0	0.0%
Other	0.0	0.0	0.0%
Total	**458.6**	**458.6**	**0.0%**

Note: In this table, “Non-Hydro RE” includes biomass, geothermal, landfill gas, solar, and wind.

3.5.5 Generation Mix

In this section, we discuss the projected changes in generation mix for 2028, 2030, and 2035 for the final rule. Table 3-12 presents the projected generation and percentage changes in national generation mix by fuel type for run years 2028, 2030, and 2035. These generation mix estimates reflect limited changes in energy generation as a result of the final rule in any run year. Estimated changes in coal and natural gas use under the final rule are examined further in Section 3.5.6.

Table 3-12 2028, 2030, and 2035 Projected U.S. Generation by Fuel Type for the Baseline and the Final Rule

	Generation Mix (TWh)		Incremental Change under Final Rule	
	Baseline	Final Rule	TWh	%
		2028		
Coal	472	472	-0.1	0.0%
Natural Gas	1,652	1,652	0.1	0.0%
Oil/Gas Steam	26	26	0.0	0.0%
Non-Hydro RE	1,141	1,141	0.0	0.0%
Hydro	293	293	0.0	0.0%
Energy Storage	53	53	0.0	0.1%
Nuclear	751	751	0.0	0.0%
Other	31	31	0.0	0.0%
Total	**4,418**	**4,418**	**0.0**	**0.0%**
		2030		
Coal	410	410	0.0	0.0%
Natural Gas	1,670	1,670	0.0	0.0%
Oil/Gas Steam	25	25	0.0	0.0%
Non-Hydro RE	1,329	1,329	0.0	0.0%
Hydro	298	298	0.0	0.0%
Energy Storage	69	69	0.0	0.0%
Nuclear	729	729	0.0	0.0%
Other	31	31	0.0	0.0%
Total	**4,560**	**4,560**	**0.0**	**0.0%**
		2035		
Coal	236	236	-0.1	0.0%
Natural Gas	1,344	1,344	0.0	0.0%
Oil/Gas Steam	8	8	0.0	-0.4%
Non-Hydro RE	2,229	2,229	0.0	0.0%
Hydro	319	319	0.0	0.0%
Energy Storage	148	148	0.1	0.1%
Nuclear	667	667	0.0	0.0%
Other	31	31	0.0	0.0%
Total	**4,981**	**4,981**	**0.0**	**0.0%**

Note: In this table, “Non-Hydro RE” includes biomass, geothermal, landfill gas, solar, and wind.

3.5.6 Coal and Natural Gas Use for the Electric Power Sector

In this section we discuss the estimated changes in coal use and natural gas use in 2028, 2030, and 2035. Table 3-13 and Table 3-14 present percentage changes in national coal usage by EGUs by coal supply region and coal rank, respectively. These fuel use estimates show small changes in national coal use in the final rule relative to the baseline in all run years. Additionally, the final rule is not projected to result in significant coal switching between supply regions or coal rank.

Table 3-13 2028, 2030, and 2035 Projected U.S. Power Sector Coal Use by Coal Supply Region for the Baseline and the Final Rule

Region	Year	Million Tons		% Change under Final Rule
		Baseline	Final Rule	
Appalachia	**2028**	39.8	39.8	0.1%
Interior		37.8	37.8	-0.1%
Waste Coal		7.3	7.3	0.0%
West		166.1	166.0	-0.1%
Total		**250.9**	**250.8**	**0.0%**
Appalachia	**2030**	38.8	38.8	0.0%
Interior		35.1	35.1	0.0%
Waste Coal		7.1	7.1	0.0%
West		141.5	141.5	0.0%
Total		**222.5**	**222.5**	**0.0%**
Appalachia	**2035**	31.8	31.9	0.1%
Interior		19.4	19.4	-0.1%
Waste Coal		6.8	6.8	0.0%
West		89.0	89.1	0.1%
Total		**147.1**	**147.2**	**0.0%**

Table 3-14 2028, 2030, and 2035 Projected U.S. Power Sector Coal Use by Rank for the Baseline and the Final Rule

Rank	Year	Million Tons Baseline	Million Tons Final Rule	% Change under Final Rule
Bituminous	**2028**	72.1	72.1	0.00%
Subbituminous		145.1	145.1	0.00%
Lignite		32.5	32.3	-0.60%
Total		**249.6**	**249.5**	**0.00%**
Bituminous	**2030**	62.8	62.8	0.00%
Subbituminous		125.8	125.8	0.00%
Lignite		29.3	29.3	0.00%
Total		**218**	**218**	**0.00%**
Bituminous	**2035**	42.4	42.4	0.00%
Subbituminous		74.1	74.2	0.10%
Lignite		24.5	24.5	0.00%
Total		**140.9**	**141**	**0.00%**

Table 3-15 presents the projected changes in national natural gas usage by EGUs in the 2028, 2030, and 2035 run years. These fuel use estimates reflect negligible changes in projected gas generation in 2028, 2030, and 2035.

Table 3-15 2028, 2030, and 2035 Projected U.S. Power Sector Natural Gas Use for the Baseline and the Final Rule

Year	Trillion Cubic Feet Baseline	Trillion Cubic Feet Final Rule	% Change under Final Rule
2028	11.6	11.6	0.0%
2030	11.7	11.7	0.0%
2035	9.3	9.3	0.0%

3.5.7 Fuel Price, Market, and Infrastructure

The projected impacts of the final rule on coal and natural gas prices are presented below in Table 3-16 and Table 3-17, respectively. As with the projected impact of the final rule on fuel use, there is no significant change projected for minemouth and delivered coal prices due to the final rule.

Table 3-16 2028, 2030, and 2035 Projected Minemouth and Power Sector Delivered Coal Price (2019 dollars) for the Baseline and the Final Rule

	Year	$/MMBtu		% Change under Final Rule
		Baseline	Final Rule	
Minemouth	2028	0.98	0.98	0.0%
Delivered		1.54	1.54	0.0%
Minemouth	2030	1.02	1.02	0.0%
Delivered		1.56	1.56	0.0%
Minemouth	2035	1.07	1.07	0.0%
Delivered		1.55	1.55	0.0%

Consistent with the projection of no significant change in natural gas use under the final rule, Henry Hub and power sector delivered natural gas prices are not projected to significantly change under the final rule over the period analyzed. Table 3-17 summarizes the projected impacts on Henry Hub and delivered natural gas prices in 2028, 2030, and 2035.

Table 3-17 2028, 2030, and 2035 Projected Henry Hub and Power Sector Delivered Natural Gas Price (2019 dollars) for the Baseline and the Final Rule

	Year	$/MMBtu		% Change under Final Rule
		Baseline	Final Rule	
Henry Hub	2028	2.78	2.78	0.0%
Delivered		2.84	2.84	0.0%
Henry Hub	2030	2.89	2.89	0.0%
Delivered		2.95	2.95	0.0%
Henry Hub	2035	2.87	2.87	0.0%
Delivered		2.88	2.88	0.0%

3.5.8 Retail Electricity Prices

EPA estimated the change in the retail price of electricity (2019 dollars) using the Retail Price Model (RPM).[48] The RPM was developed by ICF for EPA and uses the IPM estimates of changes in the cost of generating electricity to estimate the changes in average retail electricity prices. The prices are average prices over consumer classes (i.e., consumer, commercial, and industrial) and regions, weighted by the amount of electricity used by each class and in each region. The RPM combines the IPM annual cost estimates in each of the 64 IPM regions with

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[48] See documentation available at: *https://www.epa.gov/airmarkets/retail-price-model*.

EIA electricity market data for each of the 25 electricity supply regions (shown in Figure 3-1) in the electricity market module of the National Energy Modeling System (NEMS).[49]

Table 3-18, Table 3-19, and Table 3-20 present the projected percentage changes in the retail price of electricity for the regulatory control alternatives in 2028, 2030, and 2035, respectively. Consistent with other projected impacts presented above, the projected impacts on average retail electricity prices at both the national and regional level are projected to be small in all run years.

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[49] See documentation available at: *https://www.eia.gov/outlooks/aeo/nems/documentation/electricity/pdf/EMM_2022.pdf*.

Table 3-18 Projected Average Retail Electricity Price by Region for the Baseline and under the Final Rule, 2028

All Sectors	2028 Average Retail Electricity Price (2019 mills/kWh)		
Region	**Baseline**	**Final Rule**	**% Change under Final Rule**
TRE	73.4	73.4	0.0%
FRCC	96.4	96.4	0.0%
MISW	92.3	92.3	0.0%
MISC	87.9	88.0	0.2%
MISE	95.2	95.2	0.0%
MISS	81.3	81.3	0.0%
ISNE	141.8	141.8	0.0%
NYCW	208.4	208.4	0.0%
NYUP	121.5	121.5	0.0%
PJME	116.9	116.9	0.0%
PJMW	90.4	90.4	0.0%
PJMC	72.4	72.4	0.0%
PJMD	70.8	70.8	0.0%
SRCA	94.7	94.7	0.0%
SRSE	96.7	96.7	0.0%
SRCE	71.6	71.6	0.0%
SPPS	75.3	75.3	0.0%
SPPC	98.5	98.4	0.0%
SPPN	64.1	64.1	0.0%
SRSG	101.3	101.3	0.0%
CANO	138.7	138.7	0.0%
CASO	170.5	170.5	0.0%
NWPP	75.0	75.4	0.5%
RMRG	96.4	96.4	0.0%
BASN	96.8	96.8	0.0%
National	97.1	97.1	0.0%

Table 3-19 Projected Average Retail Electricity Price by Region for the Baseline and under the Final Rule, 2030

All Sectors	2030 Average Retail Electricity Price (2019 mills/kWh)		
Region	**Baseline**	**Final Rule**	**% Change under Final Rule**
TRE	73.3	73.3	0.0%
FRCC	97.6	97.6	0.0%
MISW	93.2	93.2	0.0%
MISC	91.3	91.5	0.2%
MISE	109.4	109.4	0.0%
MISS	85.7	85.7	0.0%
ISNE	156.6	156.6	0.0%
NYCW	210.3	210.3	0.0%
NYUP	125.7	125.7	0.0%
PJME	109.9	109.9	0.0%
PJMW	97.3	97.3	0.0%
PJMC	89.3	89.3	0.0%
PJMD	76.5	76.5	0.0%
SRCA	92.1	92.2	0.0%
SRSE	94.7	94.7	0.0%
SRCE	70.7	70.7	0.0%
SPPS	77.7	77.8	0.0%
SPPC	97.3	97.3	0.0%
SPPN	65.1	65.1	0.0%
SRSG	101.7	101.6	0.0%
CANO	142.9	142.9	0.0%
CASO	173.8	173.9	0.0%
NWPP	81.6	81.7	0.1%
RMRG	100.7	100.7	0.0%
BASN	96.3	96.3	0.0%
National	99.6	99.6	0.0%

Table 3-20 Projected Average Retail Electricity Price by Region for the Baseline and under the Final Rule, 2035

All Sectors	2035 Average Retail Electricity Price (2019 mills/kWh)		
Region	**Baseline**	**Final Rule**	**% Change under Final Rule**
TRE	78.4	78.4	0.0%
FRCC	91.9	91.9	0.0%
MISW	84.5	84.5	0.0%
MISC	81.5	81.5	0.1%
MISE	95.7	95.7	0.0%
MISS	79.2	79.2	0.0%
ISNE	156.1	155.8	-0.2%
NYCW	208.9	208.9	0.0%
NYUP	124.6	124.6	0.0%
PJME	108.5	108.5	0.0%
PJMW	91.8	91.8	0.0%
PJMC	75.1	75.1	0.0%
PJMD	71.4	71.4	0.0%
SRCA	89.4	89.4	0.0%
SRSE	90.1	90.1	0.0%
SRCE	67.1	67.1	0.0%
SPPS	69.5	69.5	0.0%
SPPC	80.4	80.4	0.0%
SPPN	63.0	63.0	0.0%
SRSG	103.4	103.4	0.0%
CANO	139.5	139.5	0.0%
CASO	172.8	172.8	0.0%
NWPP	78.5	78.9	0.4%
RMRG	93.4	93.4	0.0%
BASN	96.9	97.0	0.0%
National	95.9	95.9	0.0%

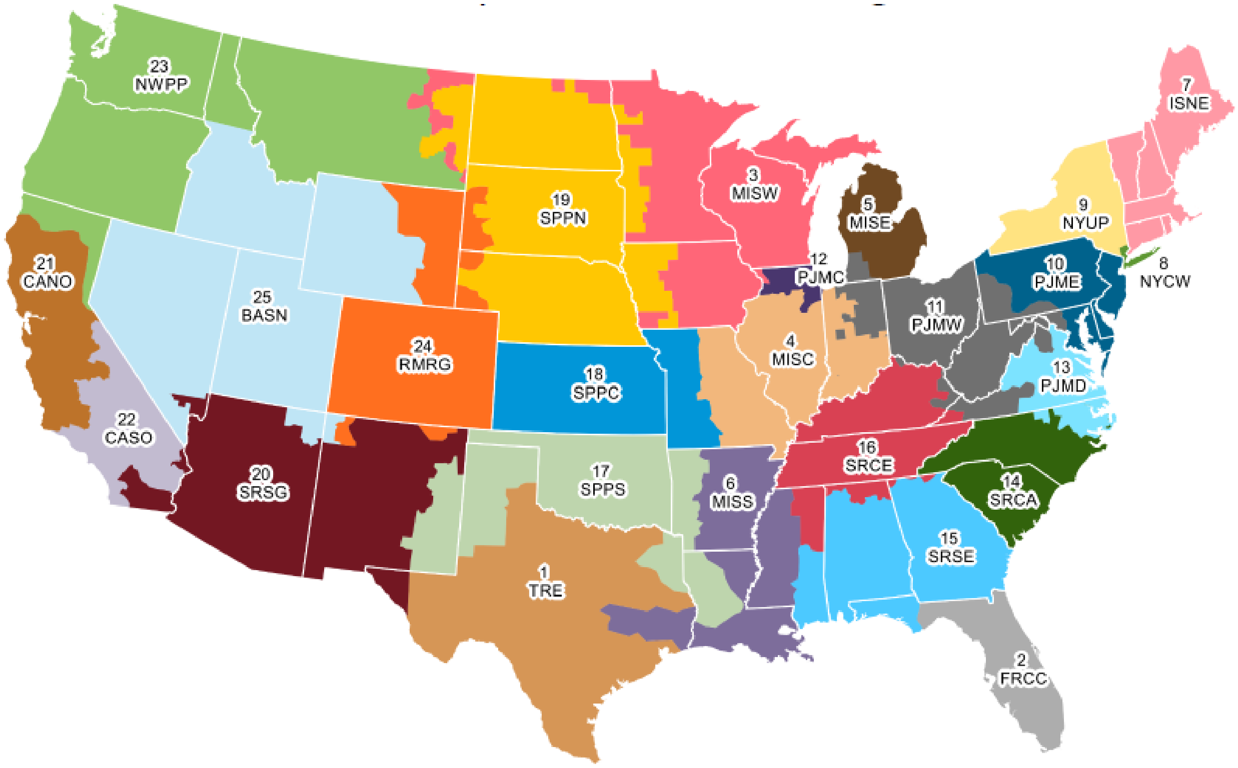

Figure 3-1 Electricity Market Module Regions
Source: EIA (*http://www.eia.gov/forecasts/aeo/pdf/nerc_map.pdf*)

3.6 Limitations of Analysis and Key Areas of Uncertainty

EPA's power sector modeling is based on expert judgment of various input assumptions for variables whose outcomes are uncertain. As a general matter, the Agency reviews the best available information from engineering studies of air pollution controls and new capacity construction costs to support a reasonable modeling framework for analyzing the cost, emission changes, and other impacts of regulatory actions for EGUs. The annualized cost of the final rule, as quantified here, is EPA's best assessment of the cost of implementing the rule on the power sector.

The IPM-projected annualized cost estimates of private compliance costs provided in this analysis are meant to show the increase in production (generating) costs to the power sector in response to the finalized requirements. To estimate these annualized costs, as discussed earlier, EPA uses a conventional and widely accepted approach that applies a capital recovery factor (CRF) multiplier to capital investments and adds that to the annual incremental operating expenses to calculate annual costs. The CRF is derived from estimates of the cost of capital (private discount rate), the amount of insurance coverage required, local property taxes, and the life of capital. The private compliance costs presented earlier are EPA's best estimate of the direct private compliance costs of the rule.

In addition, there are several key areas of uncertainty related to the electric power sector that are worth noting, including:

- **Electricity demand:** The analysis includes an assumption for future electricity demand. To the extent electricity demand is higher and lower, it may increase/decrease the projected future composition of the fleet.
- **Natural gas supply and demand:** To the extent natural gas supply and delivered prices are higher or lower, it would influence the use of natural gas for electricity generation and overall competitiveness of other EGUs (e.g., coal and nuclear units).
- **Longer-term planning by utilities:** Many utilities have announced long-term clean energy and/or climate commitments, with a phasing out of large amounts of coal capacity by 2030 and continuing through 2050. These announcements are not necessarily reflected in the baseline and may alter the amount of coal capacity projected in the baseline that would be covered under this rule.
- **FPM emissions and control:** As discussed above, the baseline fPM emissions rates for each unit are based on the analysis documented in the memorandum titled "2024 Update to the 2023 Proposed Technology Review for the Coal- and Oil-Fired EGU Source Category." For those EGUs with rates greater than the final limit, EPA assumes that control technology summarized in Section 3.4 would be necessary to remain operational. While the baseline emissions rate for each EGU and the cost and performance assumption for each PM control technology are the best available to EPA at this time, it is possible that some EGUs may be able to achieve the revised fPM emissions limits with less costly control technology (e.g., an ESP upgrade instead of a fabric filter installation). It is also possible that EPA's cost assumptions reflect higher technology costs than might be incurred by EGUs.

These are key uncertainties that may affect the overall composition of electric power generation fleet and/or compliance with the finalized emissions limits and could thus have an effect on the estimated costs and impacts of this action. While it is important to recognize these key areas of uncertainty, they do not change EPA's overall confidence in the projected impacts of the final rule presented in this section. EPA continues to monitor industry developments and makes appropriate updates to the modeling platforms in order to reflect the best and most current data available.

Estimated impacts of the Revised 2023 and Later Model Year Light-Duty Vehicle GHG Emissions Standards are captured in the baseline,[50] while estimated impacts of the Proposed Rule: Model Years 2027 and Later Light-Duty and Medium-Duty Vehicle Emissions Standards are not captured in the baseline.[51] The latter rule (in its proposal) is projected to increase the total demand for electricity by 0.4 percent in 2030 and 3.4 percent in 2040 relative to the baseline electricity demand projections assumed in this analysis. Estimated impacts of the 2023 Final Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review are also not included in this analysis. The RIA for oil and natural gas sector rule projected small increases in the price of natural gas as result of the requirements (U.S. EPA, 2023c). All else equal, inclusion of these two programs would likely result in a modest increase in the fPM reductions and total cost of compliance for this rule. While we might see less retired capacity in the baseline due to higher electricity demand, and thus more PM controls under the RTR, the magnitude of the potential incremental impacts would likely be very small.

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[51] 88 FR 29184.

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BENEFITS ANALYSIS

4.1 Introduction

This rule is projected to reduce emissions of Hg and non-Hg HAP metals, fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and carbon dioxide (CO_2) nationally. The projected reductions in Hg are expected to reduce the bioconcentration of MeHg in fish. Subsistence fishing is associated with vulnerable populations, including minorities and those of low socioeconomic status. Further reductions in Hg emissions should reduce fish concentrations and exposure to HAP particularly for the subsistence fisher sub-population. The projected reductions in HAP emissions should help EPA maintain an ample margin of safety by reducing exposure to MeHg and carcinogenic HAP metals.

Regarding the potential health and ecological benefits of the rule from projected HAP reductions, we note that these are discussed only qualitatively and not quantitatively. Exposure to the HAP emitted by the source category, depending on the exposure duration and level of exposure, is associated with a variety of adverse health effects. These adverse health effects may include chronic health disorders (e.g., irritation of the lung, skin, and mucus membranes; decreased pulmonary function, pneumonia, or lung damage; detrimental effects on the central nervous system; cardiovascular disease; damage to the kidneys; and alimentary effects such as nausea and vomiting), adverse neurodevelopmental impacts, and increased risk of cancer. See 76 FR 25003–25005 for a fuller discussion of the health effects associated with HAP.

The analysis of the overall EGU sector completed for EPA's review of the 2020 appropriate and necessary finding (2023 Final A&N Review) identified significant reductions in cardiovascular and neuro-developmental effects from exposure to MeHg (88 FR 13956). However, the amount of Hg reduction projected under this rule is a fraction of the Hg estimates used in the 2023 Final A&N Review. Overall, the uncertainty associated with modeling potential benefits of Hg reduction for fish consumers would be sufficiently large as to compromise the utility of those benefit estimates—though importantly, such uncertainty does not decrease our confidence that reductions in emissions should result in reduced exposures of HAP to the general population, including MeHg exposures to subsistence fishers located near these facilities. Further, estimated risks from exposure to non-Hg HAP metals were not expected to exceed acceptable levels, although we note that these emissions reductions should result in decreased exposure to HAP for individuals living near these facilities.

ReducingPM$_{2.5}$ and SO$_2$ emissions is expected to reduce ground-level PM$_{2.5}$ concentrations. Reducing NO$_X$ emissions is expected to reduce both ground-level ozone and PM$_{2.5}$ concentrations. Below we present the estimated number and economic value of these avoided PM$_{2.5}$ and ozone-attributable premature deaths and illnesses. We also present the estimated monetized climate and health benefits associated with emission reductions projected under the final rule.

In addition to reporting results, this section details the methods used to estimate the benefits to human health of reducing concentrations of PM$_{2.5}$ and ozone resulting from the projected emissions reductions. This analysis uses methods for determining air quality changes that have been used in the RIAs from multiple previous proposed and final rules (U.S. EPA, 2019b, 2020a, 2020b, 2021a, 2022c), including the RIA for the proposal of this rule (U.S. EPA, 2023b). The approach involves two major steps: (1) developing spatial fields of air quality across the U.S. for a baseline scenario and the final rule for 2028, 2030, and 2035 using nationwide photochemical modeling and related analyses (see Air Quality Modeling Appendix, Appendix A, for more details); and (2) using these spatial fields in BenMAP-CE to quantify the benefits under the final rule and each year as compared to the baseline in that year.[52] See Section 4.3.3 for more detail on BenMAP-CE. When estimating the value of improved air quality over a multi-year time horizon, the analysis applies population growth and income growth projections for each future year through 2037 and estimates of baseline mortality incidence rates at five-year increments.

Additionally, elevated concentrations of GHGs in the atmosphere have been warming the planet, leading to changes in the Earth's climate including changes in the frequency and intensity of heat waves, precipitation, and extreme weather events, rising seas, and retreating snow and ice. The well-documented atmospheric changes due to anthropogenic GHG emissions are changing the climate at a pace and in a way that threatens human health, society, and the natural environment. There will likely be important climate benefits associated with the CO$_2$ emissions

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[52] Note we do not perform air quality analysis on the less stringent regulatory option because it has no quantified emissions reductions associated with the finalized requirements for CEMS and the removal of startup definition number two.

reductions expected from this rule. In this RIA, we monetize climate benefits from reducing emissions of CO_2 using estimates of the SC-CO_2.

EPA is unable to quantify and monetize the potential benefits of requiring facilities to utilize CEMS rather than continuing to allow the use of quarterly testing, but the requirement has been considered qualitatively. Relative to periodic testing practices, continuous monitoring of fPM will result in increased transparency, as well as potential emissions reductions from identifying problems more rapidly. Hence, the final rule may induce further reductions of fPM and non-Hg HAP metals than we project in this RIA, and these reductions would likely lead to additional health benefits. However, due to data and methodological challenges, EPA is unable to quantify these potential additional reductions. The continuous monitoring of fPM required in this rule is also likely to provide several additional important benefits to the public which are not quantified in this rule, including greater certainty, accuracy, transparency, and granularity in fPM emissions information than exists today. Additionally, to the extent that the removal of the second definition of startup leads to actions that may otherwise not occur absent this final rule, there may be beneficial impacts we are unable to estimate. Though the rule is likely to also yield positive benefits associated with reducing pollutants other than Hg, non-Hg HAP metals, $PM_{2.5}$, ozone, and CO_2, time, resource, and data limitations prevented us from quantifying and estimating the economic value of those reductions. Specifically, in this RIA EPA does not monetize health benefits of reducing direct exposure to NO_2 and SO_2 nor ecosystem effects and visibility impairment associated with changes in air quality. We qualitatively discuss these unquantified impacts in this section of the RIA.

4.2 Hazardous Air Pollutant Benefits

This final rule is projected to reduce emissions of Hg and non-Hg HAP metals. Specifically, projected reductions in Hg are expected to help reduce exposure to MeHg for sub-populations that rely on subsistence fishing. In addition, projected emissions reductions should also reduce exposure to non-Hg HAP metals including carcinogens such as nickel, arsenic, and hexavalent chromium, for residents located in the vicinity of these facilities.

4.2.1 Hg

Hg is a persistent, bioaccumulative toxic metal that is emitted from power plants in three forms: gaseous elemental Hg (Hg0), oxidized Hg compounds (Hg+2), and particle-bound Hg (HgP). Elemental Hg does not quickly deposit or chemically react in the atmosphere, resulting in residence times that are long enough to contribute to global scale deposition. Oxidized Hg and HgP deposit quickly from the atmosphere impacting local and regional areas in proximity to sources. MeHg is formed by microbial action in the top layers of sediment and soils, after Hg has precipitated from the air and deposited into waterbodies or land. Once formed, MeHg is taken up by aquatic organisms and bioaccumulates up the aquatic food web. Larger predatory fish may have MeHg concentrations many times that of the concentrations in the freshwater body in which they live (ATSDR, 2022). MeHg can adversely impact ecosystems and wildlife.

Human exposure to MeHg is known to have several adverse neurodevelopmental impacts, such as IQ loss measured by performance on neurobehavioral tests, particularly on tests of attention, fine motor-function, language, and visual spatial ability. In addition, evidence in humans and animals suggests that MeHg can have adverse effects on both the developing and the adult cardiovascular system, including fatal and non-fatal ischemic heart disease (IHD). Further, nephrotoxicity, immunotoxicity, reproductive effects (impaired fertility), and developmental effects have been observed with MeHg exposure in animal studies (ATSDR, 2022). MeHg has some genotoxic activity and is capable of causing chromosomal damage in a number of experimental systems. EPA has classified MeHg as a "possible" human carcinogen (U.S. EPA, 2001).

The projected reductions in Hg under this final rule are expected to reduce the bioconcentration of MeHg in fish due to Hg emissions from MATS-affected sources. Risk from near-field deposition of Hg to subsistence fishers has previously been evaluated, using a site-specific assessment of a lake near three lignite-fired facilities (U.S. EPA, 2020d). The results suggest that MeHg exposure to subsistence fishers from lignite-fired units is below the current RfD for MeHg neurodevelopmental toxicity or IQ loss, with an estimated hazard quotient (HQ) of 0.06. In general, EPA believes that exposures at or below the RfD are unlikely to be associated with appreciable risk of deleterious effects.

Regarding the potential magnitude of human health risk reductions and benefits associated with this rule, we make the following observations. All of the exposure results generated as part of the 2020 Residual Risk analysis were below the presumptive acceptable cancer risk threshold and noncancer health-based thresholds. While these results suggest that the residual risks from HAP exposure are low, we do recognize that this regulation should still reduce exposure to HAP.

Regarding potential benefits of the rule to the general population of fish consumers, while we note that the analysis of the overall EGU sector completed for the 2023 Final A&N Review did identify significant reductions in cardiovascular and neuro-developmental effects, given the substantially smaller Hg reduction associated with this rule (approximately 900 to 1000 pounds per year under the final rule compared to the approximately 29 tons of Hg evaluated in the 2023 Final A&N Review), overall uncertainty associated with modeling potential benefits for the broader population of fish consumers would be sufficiently large as to compromise the utility of those benefit estimates.

Despite the lack of quantifiable risks from Hg emissions, reductions would be expected to have some impact (reduction) on the overall MeHg burden in fish for waterbodies near covered facilities. In the appropriate and necessary determination, EPA illustrated that the burden of Hg exposure is not equally distributed across the population and that some subpopulations bore disproportionate risks associated with exposure to emissions from U.S. EGUs. High levels of fish consumption observed with subsistence fishing were associated with vulnerable populations, including minorities and those with low socioeconomic status (SES). Reductions in Hg emissions should reduce MeHg exposure and body burden for subsistence fishers.

U.S. EGU Hg emissions can lead to increased deposition of Hg to nearby waterbodies. Deposition of Hg to waterbodies can also have an impact on ecosystems and wildlife. Hg contamination is present in all environmental media with aquatic systems being particularly impacted due to bioaccumulation. Bioaccumulation refers to the net uptake of a contaminant from all possible pathways and includes the accumulation that may occur by direct exposure to contaminated media as well as uptake from food. Atmospheric Hg enters freshwater ecosystems by direct deposition and through runoff from terrestrial watersheds. Once Hg deposits, it may be converted to organic MeHg mediated primarily by sulfate-reducing bacteria. Methylation is enhanced in anaerobic and acidic environments, greatly increasing Hg toxicity and potential to bioaccumulate in aquatic foodwebs (Munthe et al. 2007). The highest levels of MeHg accumulation are most often measured in fish eating (piscivorous) animals and those which prey on other fish eaters. In laboratory studies, adverse effects from exposure to MeHg in wildlife have been observed in fish, mink, otters, and several avian species at exposure levels as low as 0.25 micrograms of MeHg per gram of body weight (U.S. EPA, 1997). The risk of Hg exposure may also extend to insectivorous terrestrial species such as songbirds, bats, spiders, and amphibians that receive Hg deposition or from aquatic systems near the forest areas they inhabit (Bergeron et al., 2010a, 2010b; Cristol et al., 2008; Rimmer et al., 2005; Wada et al., 2009; Wada et al., 2010)

The projected emissions reductions of Hg are expected to lower deposition of Hg into ecosystems and reduce U.S. EGU attributable bioaccumulation of MeHg in wildlife, particularly for areas closer to the effected units subject to near-field deposition. Because Hg emissions from U.S. EGUs can both become deposited in or bioaccumulate in organisms living in foreign and international waters, reduction of Hg emissions from U.S. EGUs could lead to some benefits internationally as well. EPA is currently unable to quantify or monetize such effects.

4.2.2 Non-Hg HAP Metal

U.S. EGUs are the largest source of selenium emissions and a major source of non-Hg HAP metals emissions including arsenic, chromium, cobalt, and nickel. Additionally, U.S. EGUs emit beryllium, cadmium, lead, and manganese. These emissions include HAP metals that are persistent and bioaccumulate (arsenic, cadmium, and lead) and others have cancer-causing potential (beryllium, cadmium, chromium, cobalt, lead, and nickel). PM controls are expected to reduce HAP metals emissions and therefore reduce exposure to HAP metals for the general population including those living near these facilities.

Exposure to these HAP metals, depending on exposure duration and levels of exposures, is associated with a variety of adverse health effects. These adverse health effects may include chronic health disorders (e.g., irritation of the lung, skin, and mucus membranes; decreased pulmonary function, pneumonia, or lung damage; detrimental effects on the central nervous system; damage to the kidneys; and alimentary effects such as nausea and vomiting). As of 2023, three of the key HAP metals or their compounds emitted by EGUs (arsenic, chromium as hexavalent chromium, and nickel as nickel refinery dust and nickel subsulfide) are classified as carcinogenic to humans. Specifically, hexavalent chromium is carcinogenic to humans by the inhalation of exposure. Two other key HAP emitted by EGUs (cadmium and selenium as selenium sulfide) are classified as probable human carcinogens.

U.S. EGU source category emissions of non-Hg HAP are not expected to exceed 1 in a million for inhalation cancer risk for those facilities impacted by the control requirements in the final rule. Further, cancer risk was determined to fall within the acceptable range for multipathway exposure to the persistent and bioaccumulative non-Hg HAP metals, such as arsenic, cadmium, and lead.[53] However, the projected emissions reductions should reduce levels of exposure to carcinogenic HAP in communities near the impacted facilities.

EPA also evaluated the potential for noncancer risks from exposure to non-Hg HAP metals in 2020. To address the risk from chronic inhalation exposure to multiple pollutants, we aggregated the health risks associated with pollutants that affect the same target organ. Further, we examined the potential for adverse health effects from acute inhalation exposure to individual pollutants. Lastly, we also examined the potential for health impacts stemming from multiple pathways of exposure for arsenic, cadmium, and lead. The estimated risks were not expected to exceed current health thresholds for adverse effects (U.S. EPA, 2020d). Therefore, we are unable to identify or quantify noncancer benefits from the projected non-Hg HAP metals emission reductions, although we do note that emissions reductions associated with this rule should further reduce exposure to these non-Hg HAP metals in communities near these facilities.

In the subsequent sections, we describe the health effects associated with the main non-Hg HAP metals of concern: antimony (Section 4.2.2.1), arsenic (Section 4.2.2.2), beryllium (Section 4.2.2.3), cadmium (Section 4.2.2.4), chromium (Section 4.2.2.5), cobalt (Section 4.2.2.6), lead (Section 4.2.2.7), manganese (Section 4.2.2.8), nickel (Section 4.2.2.9), and selenium (Section 4.2.2.10). This final rule is projected to reduce at least four to seven tons of non-Hg HAP metals emissions per year. With the data available, it was not possible to estimate the change in emissions of each individual HAP.

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[53] *https://www.regulations.gov/document/EPA-HQ-OAR-2018-0794-0014.*

4.2.2.1 Antimony

Antimony (Sb), a naturally occurring element, is released into the environment by incinerators and coal-burning power plants and is considered toxic through the oral, inhalation and dermal routes. The respiratory tract is most sensitive to the effects of inhaled Sb. Acute (short-term) inhalation exposure to Sb results in effects including respiratory irritation, pulmonary inflammation, increases in lung macrophages and impaired lung clearance. Acute high-level inhalation exposure to Sb has been associated with degeneration in heart and EKG alterations (ATSDR, 2019). Chronic (long-term) inhalation exposure to Sb has been associated with interstitial fibrosis and lung neoplasms. EPA has not assessed Sb for carcinogenicity under the IRIS program (U.S. EPA, 1987a)

4.2.2.2 Arsenic

Arsenic (As), a naturally occurring element, is found throughout the environment, and is considered toxic through the oral, inhalation and dermal routes. Acute (short-term) high-level inhalation exposure to as dust or fumes has resulted in gastrointestinal effects (nausea, diarrhea, abdominal pain, and gastrointestinal hemorrhage); central and peripheral nervous system disorders have occurred in workers acutely exposed to inorganic As. Chronic (long-term) inhalation exposure to inorganic as in humans is associated with irritation of the skin and mucous membranes. Chronic inhalation can also lead to conjunctivitis, irritation of the throat and respiratory tract, and perforation of the nasal septum (ATSDR, 2007). Chronic oral exposure has resulted in gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, and liver or kidney damage in humans. Inorganic As exposure in humans, by the inhalation route, has been shown to be strongly associated with lung cancer, while ingestion of inorganic as in humans has been linked to a form of skin cancer and also to bladder, liver, and lung cancer. EPA has classified inorganic arsenic as a Group A, human carcinogen (U.S. EPA, 1995a).

4.2.2.3 Beryllium

The major sources of beryllium emissions are from the combustion of fossil fuels like coal and fuel oil. Acute exposure to beryllium compounds can lead to skin irritation, dermatitis, upper and lower airway inflammation, and pulmonary edema (Jakubowski and Palczynski, 2007). Inhalation of beryllium compounds can lead to the storage of the compound in the lung tissue and cause a specific lung disease called chronic beryllium disease (CBD) which starts with beryllium sensitization (Seidler et al., 2012). Common symptoms of CBD include fatigue, coughing, weight loss, and fevers. Research has shown that beryllium exposure causes cancer in rats and monkeys, and while some research shows a relationship with cancer in humans, it is not definitive. Beryllium is considered to be a Group B1 probable human carcinogen by EPA (U.S. EPA, 1998a).

4.2.2.4 Cadmium

The main sources of cadmium in air are the burning of fossil fuels and the incineration of municipal waste. Acute inhalation in humans causes adverse effects in the lung, such as pulmonary irritation. Chronic inhalation in humans can result in a build-up of cadmium in the kidney, and if sufficiently high, may result in kidney disease. Animal studies indicate that cadmium may cause adverse developmental effects, including reduced body weight, skeletal malformation, and altered behavior and learning (ATSDR, 2012a). Lung cancer has been found in some studies of workers exposed to Cd in the air and studies of rats that inhaled cadmium. EPA has classified cadmium as a probable human carcinogen (Group B1) (U.S. EPA, 1987b).

4.2.2.5 Chromium

Chromium (Cr) may be emitted in two forms, trivalent Cr (Cr+3) or hexavalent Cr (Cr+6). The respiratory tract is the major target organ for Cr+6 toxicity, for acute and chronic inhalation exposures. Shortness of breath, coughing, and wheezing have been reported from acute exposure to Cr+6, while perforations and ulcerations of the septum, bronchitis, decreased pulmonary function, pneumonia, and other respiratory effects have been noted from chronic exposures. Animal studies have reported adverse reproductive effects from exposure to Cr+6. Human and animal studies have clearly established the carcinogenic potential of Cr+6 by the inhalation route, resulting in an increased risk of lung cancer (ATSDR, 2012b). EPA has classified Cr+6 as a Group A, human carcinogen (U.S. EPA, 1998c). Trivalent Cr is less toxic than Cr+6. The respiratory tract is also the major target organ for Cr+3 toxicity, similar to Cr+6. EPA has not classified Cr+3 with respect to carcinogenicity (U.S. EPA, 1998b).

4.2.2.6 Cobalt

Cobalt (Co) and cobalt compounds are naturally occuring and possess physiochemical properties like iron and nickel. The primary anthropogenic sources of Co in the environment are from the burning of fossil fuels, mining and smelting of Co ores, and processing of cobalt-containing alloys. Exposure to Co in the general population occurs through inhalation of ambient air or ingestion of food and drinking water. The respiratory tract is most sensitive to the effects of inhaled Co. Acute (short-term) inhalation exposure to Co results in pulmonary irritation and edema. Chronic (long-term) inhalation exposure to Co results in decreased lung function, inflammation, and lesions cobalt (ATSDR, 2023a). EPA has not yet assessed Co for carcinogenicity under the IRIS program (U.S. EPA, 2008).

4.2.2.7 Lead

Lead is found naturally in ore deposits. A major source of lead in the U.S. environment has historically been from combustion of leaded gasoline, which was phased out of use after 1973. Other sources of lead have included mining and smelting of ore; manufacture of and use of lead-containing products (e.g., lead-based paints, pigments, and glazes; electrical shielding; plumbing; storage batteries; solder; and welding fluxes); manufacture and application of lead-containing pesticides; combustion of coal and oil; and waste incineration. Lead is associated with toxic effects in every organ system including adverse renal, cardiovascular, hematological, reproductive, and developmental effects. However, the major target for lead toxicity is the nervous system, both in adults and children. Long-term exposure of adults to lead at work has resulted in decreased performance in some tests that measure functions of the nervous system. Lead exposure may also cause weakness in fingers, wrists, or ankles. Lead exposure also causes small increases in blood pressure, particularly in middle-aged and older people and may also cause anemia. Children are more sensitive to the health effects of lead than adults. No safe blood lead level in children has been determined. At lower levels of exposure, lead can affect a child’s mental and physical growth. Fetuses exposed to lead in the womb may be born prematurely and have lower weights at birth. Exposure in the womb, in infancy, or in early childhood also may slow mental development and cause lower intelligence later in childhood. There is evidence that these effects may persist beyond childhood (ATSDR, 2023b). EPA has determined that lead is a probable human carcinogen (Group 2B) (U.S. EPA, 1988).

4.2.2.8 Manganese

Manganese (Mn) is a naturally occuring metal found in rock and used in steel production or as an additive in gasoline. Chronic exposure to high levels of Mn by inhalation in humans results primarily in central nervous system effects. Visual reaction time, hand steadiness, and eye-hand coordination were affected in chronically-exposed workers. Manganism, characterized by feelings of weakness and lethargy, tremors, a masklike face, and psychological disturbances, may result from chronic exposure to higher levels. Impotence and loss of libido have been noted in male workers afflicted with Manganism attributed to inhalation exposures. High levels of exposure have been associated with lung irritation and reproductive effects. In animals, nervous system and reproductive effects have been observed (ATSDR, 2012c). EPA has classified Mn in Group D, not classifiable as to carcinogenicity in humans (U.S. EPA, 1995b).

4.2.2.9 Nickel

Nickel (Ni) is found in ambient air as a result of releases from oil and coal combustion, nickel metal refining, sewage sludge incineration, manufacturing facilities, and other sources. Respiratory effects have been reported in humans from inhalation exposure to nickel. Acute exposure to nickel carbonyl has been associated with reports of pulmonary fibrosis and renal edema in both animals and humans. Chronic inhalation of nickel in workers can cause chronic bronchitis and reduced lung function (ATSDR, 2005, 2023b). Human and animal studies have reported an increased risk of lung and nasal cancers from exposure to nickle refinery dusts and nickel subsulfide. EPA has classified nickel subsulfide and nickel refinery dusts as human carcinogens and nickel carbonyl as a probable human carcinogen (U.S. EPA, 1987c, 1987d, 1987e).

4.2.2.10 Selenium

Selenium has many uses including in the electronics industry; the glass industry; in pigments used in plastics, paints, enamels, inks, and rubber; as a catalyst in the preparation of pharmaceuticals; and in special trades. Dizziness, fatigue, and irritation of mucous membranes have been reported in people exposed to high levels of selenium in the air in the workplace. High amounts of selenium have been associated with adverse reproductive effects in animal studies. However, the relevance of the effects observed in rats and monkeys to humans is not known (ATSDR, 2003). One selenium compound, selenium sulfide, is carcinogenic in animals exposed orally. EPA has classified elemental Se as a Group D2, not classifiable as to human carcinogenicity, and selenium sulfide as a Group B2, probable human carcinogen (U.S. EPA, 1991).

4.2.3 Additional HAP Benefits

As discussed in detail in the 2023 Final A&N Review, it is challenging to quantify the full range of benefits of HAP reductions. But that does not mean that these benefits are small, insignificant, or nonexistent. In the 2011 MATS RIA (U.S. EPA, 2011), EPA discussed the potential for non-monetizable benefits from effects on fish, birds, and mammals, in part represented through the commercial and recreational fishing economy. A report submitted to EPA in comments concluded that recreational and commercial fishing are substantial contributors to regional U.S. economies with dollar values in the tens of billions (IEc, 2019). At this scale of economic activity, even small shifts in consumer behavior prompted by further HAP reductions can result in substantial economic impacts.

As another example of the potential value of these emissions reductions, EPA received numerous comments in the public comment periods of past EGU HAP regulations highlighting that benefits of Hg reductions to tribal health, subsistence, fishing rights, and cultural identity, while not easily quantified or monetized, are nonetheless important to consider. Finally, EPA also qualitatively considers impacts on ecosystem services, which are generally defined as the economic benefits that individuals and organizations obtain from ecosystems. The monetization of endpoints like ecosystem services, tribal culture, and the activity related to fishing remains challenging. While EPA is not able to monetize the impacts of reduced HAP exposures projected for this rule, we note the importance of the contributions of further reductions of HAP emissions to the sustainability of these important economic and cultural values.

4.3 Criteria Pollutant Benefits

The benefits analysis presented in this section applies methods consistent with those employed most recently in the RIA for the proposed PM National Ambient Air Quality Standards (NAAQS). EPA's approach for selecting $PM_{2.5}$ and ozone-related health endpoints to quantify and monetize is summarized below and we refer readers to the referenced Health Benefits TSD for a full description of our methods (U.S. EPA, 2023a).

Estimating the health benefits of reductions in $PM_{2.5}$ and ozone exposure begins with estimating the change in exposure for each individual and then estimating the change in each individual's risks for those health outcomes affected by exposure. The benefit of the reduction in each health risk is based on the exposed individual's willingness to pay (WTP) for the risk change, assuming that each outcome is independent of one another. The greater the magnitude of the risk reduction from a given change in concentration, the greater the individual's WTP, all else equal. The social benefit of the change in health risks equals the sum of the individual WTP estimates across all of the affected individuals residing in the U.S.[54]

We conduct this analysis by adapting primary research—specifically, air pollution epidemiology studies and economic value studies—from similar contexts. This approach is sometimes referred to as "benefits transfer." Below we describe the procedure we follow for: (1) developing spatial fields of air quality for the baseline and final rule (2) selecting air pollution health endpoints to quantify; (3) calculating counts of air pollution effects using a health impact function; (4) specifying the health impact function with concentration-response parameters drawn from the epidemiological literature to calculate the economic value of the health impacts. We estimate the quantity and economic value of air pollution-related effects using a "damage-function." This approach quantifies counts of air pollution-attributable cases of adverse health outcomes and assigns dollar values to those counts, while assuming that each outcome is independent of one another.

As structured, the final rule would affect the distribution of ozone and $PM_{2.5}$ concentrations in much of the U.S. This RIA estimates avoided ozone- and $PM_{2.5}$-related health impacts that are distinct from those reported in the RIAs for both ozone and PM NAAQS (U.S. EPA, 2015, 2022d) The ozone and PM NAAQS RIAs illustrate, but do not predict, the benefits and costs of strategies that states may choose to enact when implementing a revised NAAQS; these costs and benefits are illustrative and cannot be added to the costs and benefits of policies that prescribe specific emission control measures. This RIA estimates the benefits (and costs) of specific emissions control measures. The benefit estimates are based on these modeled changes in $PM_{2.5}$ and summer season average ozone concentrations.

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[54] This RIA also reports the change in the sum of the risk, or the change in the total incidence, of a health outcome across the population. If the benefit per unit of risk is invariant across individuals, the total expected change in the incidence of the health outcome across the population can be multiplied by the benefit per unit of risk to estimate the social benefit of the total expected change in the incidence of the health outcome.

4.3.1 Air Quality Modeling Methodology

The final rule influences the level of pollutants emitted in the atmosphere that adversely affect human health, including directly emitted $PM_{2.5}$, as well as SO_2 and NO_X, which are both precursors to ambient $PM_{2.5}$. NO_X emissions are also a precursor to ambient ground-level ozone. EPA used air quality modeling to estimate changes in ozone and $PM_{2.5}$ concentrations that may occur as a result of the final rule relative to the baseline.

As described in the Air Quality Modeling Appendix (Appendix A), gridded spatial fields of ozone and $PM_{2.5}$ concentrations representing the baseline and final rule were derived from CAMx source apportionment modeling in combination with NO_X, SO_2, and primary $PM_{2.5}$ EGU emissions obtained from the outputs of the IPM runs described in Section 3 of this RIA. While the air quality modeling includes all inventoried pollution sources in the contiguous U.S., contributions from all sources other than EGUs are held constant at projected 2026 levels in this analysis, and the only changes quantified between the baseline and the final rule are those associated with the projected impacts of this final rule on EGU emissions. EPA prepared gridded spatial fields of air quality for the baseline and the final rule for two health-impact metrics: annual mean $PM_{2.5}$ and April through September seasonal average eight-hour daily maximum (MDA8) ozone (AS-MO3). These ozone and $PM_{2.5}$ gridded spatial fields cover all locations in the contiguous U.S. and were used as inputs to BenMAP-CE which, in turn, was used to quantify the benefits from this rule.

The basic methodology for determining air quality changes is the same as that used in the RIAs from multiple previous rules (U.S. EPA, 2019b, 2020a, 2020b, 2021a, 2022c). The Air Quality Modeling Appendix (Appendix A) provides additional details on the air quality modeling and the methodologies EPA used to develop gridded spatial fields of summertime ozone and annual $PM_{2.5}$ concentrations. The appendix also provides figures showing the geographical distribution of air quality changes.

4.3.2 Selecting Air Pollution Health Endpoints to Quantify

The methods used in this RIA incorporate evidence reported in the most recent completed PM Integrated Science Assessment (PM ISA) and Ozone Integrated Science Assessments (Ozone ISA) and accounts for recommendations from the Science Advisory Board (U.S. EPA, 2022e). When updating each health endpoint EPA considered: (1) the extent to which there exists a causal relationship between that pollutant and the adverse effect; (2) whether suitable epidemiologic studies exist to support quantifying health impacts; (3) and whether robust economic approaches are available for estimating the value of the impact of reducing human exposure to the pollutant. Our approach for updating the endpoints and to identify suitable epidemiologic studies, baseline incidence rates, population demographics, and valuation estimates is summarized below. Detailed descriptions of these updates are available in the Health Benefits TSD, which is in the docket for this rulemaking. The Health Benefits TSD describes the Agency's approach for quantifying the number and value of estimated air pollution-related impacts. Updates since the publication of the Health Benefits TSD are described below. In this document the reader can find the rationale for selecting health endpoints to quantify; the demographic, health and economic data used; modeling assumptions; and our techniques for quantifying uncertainty.[55]

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[55] The analysis was completed using BenMAP-CE version 1.5.8, which is a variant of the current publicly available version. We also include new estimates of the cost of asthma onset and stroke beyond those described in the Health Benefits TSD.

Table 4-1 Health Effects of $PM_{2.5}$, Ambient Ozone, and Climate Effects

Category	Effect	Effect Quantified	Effect Monetized	More Information
Premature mortality from exposure to $PM_{2.5}$	Adult premature mortality based on cohort study estimates and expert elicitation estimates (age 65-99 or age 30-99)	✓	✓	PM ISA
	Infant mortality (age <1)	✓	✓	PM ISA
Nonfatal morbidity from exposure to $PM_{2.5}$	Heart attacks (age > 18)	✓	✓[1]	PM ISA
	Hospital admissions—cardiovascular (ages 65-99)	✓	✓	PM ISA
	Emergency department visits— cardiovascular (age 0-99)	✓	✓	PM ISA
	Hospital admissions—respiratory (ages 0-18 and 65-99)	✓	✓	PM ISA
	Emergency room visits—respiratory (all ages)	✓	✓	PM ISA
	Cardiac arrest (ages 0-99; excludes initial hospital and/or emergency department visits)	✓	✓[1]	PM ISA
	Stroke (ages 65-99)	✓	✓[1]	PM ISA
	Asthma onset (ages 0-17)	✓	✓	PM ISA
	Asthma symptoms/exacerbation (6-17)	✓	✓	PM ISA
	Lung cancer (ages 30-99)	✓	✓	PM ISA
	Allergic rhinitis (hay fever) symptoms (ages 3-17)	✓	✓	PM ISA
	Lost work days (age 18-65)	✓	✓	PM ISA
	Minor restricted-activity days (age 18-65)	✓	✓	PM ISA
	Hospital admissions—Alzheimer's disease (ages 65-99)	✓	✓	PM ISA
	Hospital admissions—Parkinson's disease (ages 65-99)	✓	✓	PM ISA
	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]
	Other nervous system effects (e.g., autism, cognitive decline, dementia)	—	—	PM ISA[2]
	Metabolic effects (e.g., diabetes)	—	—	PM ISA[2]
	Reproductive and developmental effects (e.g., low birth weight, pre-term births, etc.)	—	—	PM ISA[2]
	Cancer, mutagenicity, and genotoxicity effects	—	—	PM ISA[2]
Mortality from exposure to ozone	Premature respiratory mortality based on short-term study estimates (0-99)	✓	✓	Ozone ISA
	Premature respiratory mortality based on long-term study estimates (age 30–99)	✓	✓	Ozone ISA
Nonfatal morbidity from exposure to ozone	Hospital admissions—respiratory (ages 0-99)	✓	✓	Ozone ISA
	Emergency department visits—respiratory (ages 0-99)	✓	✓	Ozone ISA
	Asthma onset (0-17)	✓	✓	Ozone ISA
	Asthma symptoms/exacerbation (asthmatics age 2-17)	✓	✓	Ozone ISA
	Allergic rhinitis (hay fever) symptoms (ages 3-17)	✓	✓	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[2]
	Metabolic effects (e.g., diabetes)	—	—	Ozone ISA[2]
	Other respiratory effects (e.g., premature aging of lungs)	—	—	Ozone ISA[2]

Table 4-1 Health Effects of $PM_{2.5}$, Ambient Ozone, and Climate Effects

Category	Effect	Effect Quantified	Effect Monetized	More Information
	Cardiovascular and nervous system effects	—	—	Ozone ISA[2]
	Reproductive and developmental effects	—	—	Ozone ISA[2]
Climate effects	Climate impacts from carbon dioxide (CO_2)	—	✓	Section 4.4
	Other climate impacts (e.g., ozone, black carbon, aerosols, other impacts)	—	—	IPCC, Ozone ISA, PM ISA

[1] Valuation estimate excludes initial hospital and/or emergency department visits.
[2] Not quantified due to data availability limitations and/or because current evidence is only suggestive of causality.

4.3.3 Calculating Counts of Air Pollution Effects Using the Health Impact Function

We use the environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) software program to quantify counts of premature deaths and illnesses attributable to photochemical modeled changes in annual mean $PM_{2.5}$ and summer season average ozone concentrations for the years 2030, 2035, and 2040 using health impact functions (Sacks et al., 2020). A health impact function combines information regarding: the concentration-response relationship between air quality changes and the risk of a given adverse outcome; the population exposed to the air quality change; the baseline rate of death or disease in that population; and the air pollution concentration to which the population is exposed.

BenMAP quantifies counts of attributable effects using health impact functions, which combine information regarding the: concentration-response relationship between air quality changes and the risk of a given adverse outcome; population exposed to the air quality change; baseline rate of death or disease in that population; and air pollution concentration to which the population is exposed.

The following provides an example of a health impact function, in this case for $PM_{2.5}$ mortality risk. We estimate counts of $PM_{2.5}$-related total deaths (y_{ij}) during each year i among adults aged 18 and older (a) in each county j in the contiguous U.S. (where $j = 1, \ldots, J$ and J is the total number of counties) as:

$$y_{ij} = \Sigma_a \, y_{ija}$$

$$y_{ija} = mo_{ija} \times (e^{\beta \cdot \Delta C_{ij}} - 1) \times P_{ija}, \qquad \text{Eq[1]}$$

where mo_{ija} is the baseline total mortality rate for adults aged a = 18-99 in county j in year i stratified in 10-year age groups, β is the risk coefficient for total mortality for adults associated with annual average $PM_{2.5}$ exposure, C_{ij} is the annual mean $PM_{2.5}$ concentration in county j in year i, and P_{ija} is the number of county adult residents aged a = 18-99 in county j in year i stratified into 5-year age groups.[56]

The BenMAP-CE tool is pre-loaded with projected population from the Woods & Poole company; cause-specific and age-stratified death rates from the Centers for Disease Control and Prevention, projected to future years; recent-year baseline rates of hospital admissions, emergency department visits and other morbidity outcomes from the Healthcare Cost and Utilization Program and other sources; concentration-response parameters from the published epidemiologic literature cited in the ISAs for fine particles and ground-level ozone; and cost of illness or WTPWTP economic unit values for each endpoint. Consistent with advice received from the U.S. EPA Science Advisory Board, EPA will substitute the existing Woods & Poole population projections with those that are not proprietary (U.S. EPA Science Advisory Board, 2024).

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

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

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[56] In this illustrative example, the air quality is resolved at the county level. For this RIA, we simulate air quality concentrations at a 12 km grid cell resolution The BenMAP-CE tool assigns the rates of baseline death and disease stored at the county level to the 12 km grid cells using an area-weighted algorithm. This approach is described in greater detail in the appendices to the BenMAP-CE user manual.

4.3.4 Calculating the Economic Valuation of Health Impacts

After quantifying the change in adverse health impacts, the final step is to estimate the economic value of these avoided impacts. The appropriate economic value for a change in a health effect depends on whether the health effect is viewed ex ante (before the effect has occurred) or ex post (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects by a small amount for a large population. The appropriate economic measure is therefore ex ante WTP for changes in risk. However, epidemiological studies generally provide estimates of the relative risks of a particular health effect avoided due to a reduction in air pollution. A convenient way to use these data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a regulation reduces the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $1,000, then the WTP for an avoided statistical premature mortality amounts to $10 million ($1,000/0.0001 change in risk). Hence, this value is population-normalized, as it accounts for the size of the population and the percentage of that population experiencing the risk. The same type of calculation can produce values for statistical incidences of other health endpoints.

For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we instead use the cost of treating or mitigating the effect to economically value the health impact. For example, for the valuation of hospital admissions we use the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These cost-of-illness (COI) estimates generally (although not in every case) understate the true value of reductions in risk of a health effect. They tend to reflect the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect.

4.3.5 Benefits Analysis Data Inputs

In Figure 4-1, we summarize the key data inputs to the health impact and economic valuation estimates, which were calculated using BenMAP-CE tool version 1.5.1. (Sacks et al., 2020). In the sections below we summarize the data sources for each of these inputs, including demographic projections, incidence and prevalence rates, effect coefficients, and economic valuation.

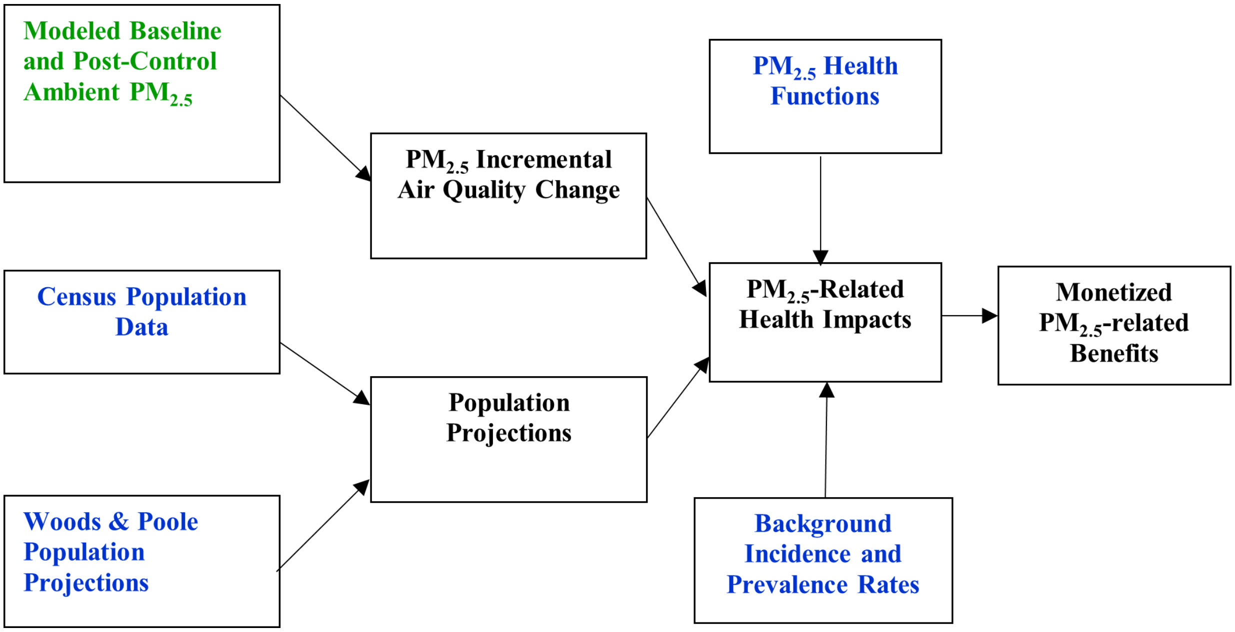

Figure 4-1 Data Inputs and Outputs for the BenMAP-CE Tool

4.3.5.1 Demographic Data

Quantified and monetized human health impacts depend on the demographic characteristics of the population, including age, location, and income. We use projections based on economic forecasting models developed by Woods & Poole, Inc. (2015). The Woods & Poole database contains county-level projections of population by age, sex, and race to 2060, relative to a baseline using the 2010 Census data. Projections in each county are determined simultaneously with every other county in the U.S. to consider patterns of economic growth and migration. The sum of growth in county-level populations is constrained to equal a previously determined national population growth, based on Bureau of Census estimates (Hollmann et al., 2000). According to Woods & Poole, linking county-level growth projections together and constraining the projected population to a national-level total growth avoids potential errors introduced by forecasting each county independently (for example, the projected sum of county-level populations cannot exceed the national total). County projections are developed in a four-stage process:

- First, national-level variables such as income, employment, and populations are forecasted.
- Second, employment projections are made for 179 economic areas defined by the Bureau of Economic Analysis, using an “export-base” approach, which relies on linking industrial-sector production of non-locally consumed production items, such as outputs from mining, agriculture, and manufacturing with the national economy. The export-based approach requires estimation of demand equations or calculation of historical growth rates for output and employment by sector.
- Third, population is projected for each economic area based on net migration rates derived from employment opportunities and following a cohort-component method based on fertility and mortality in each area.
- Fourth, employment and population projections are repeated for counties, using the economic region totals as bounds. The age, sex, and race distributions for each region or county are determined by aging the population by single year by sex and race for each year through 2060 based on historical rates of mortality, fertility, and migration.

4.3.5.2 Baseline Incidence and Prevalence Estimates

Epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the relative risk of a health effect, rather than estimating the absolute number of avoided cases. For example, a typical result might be that a 5 $\mu g/m^3$ decrease in daily $PM_{2.5}$ levels is associated with a decrease in hospital admissions of 3 percent. A baseline incidence rate, necessary to convert this relative change into a number of cases, is the estimate of the number of cases of the health effect per year in the assessment location, as it corresponds to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number. For example, if the baseline incidence rate is the number of cases per year per million people, that number must be multiplied by the millions of people in the total population.

The Health Benefits TSD (see Table 12) summarizes the sources of baseline incidence rates and reports average incidence rates for the endpoints included in the analysis. For both baseline incidence and prevalence data, we used age-specific rates where available. We applied concentration-response functions to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits. National-level incidence rates were used for most morbidity endpoints, whereas county-level data are available for premature mortality. Whenever possible, the national rates used are national averages, because these data are most applicable to a national assessment of benefits. When quantifying some endpoints, we were unable to identify a suitable administrative database supplying baseline rates of the event of interest; in these cases, we selected an incidence rate reported within the study supplying the risk estimate.

We projected mortality rates such that future mortality rates are consistent with our projections of population growth. To perform this calculation, we began first with an average of 2007-2016 cause-specific mortality rates. Using Census Bureau projected national-level annual mortality rates stratified by age range, we projected these mortality rates to 2060 in 5-year increments (U.S. Census Bureau). Further information regarding this procedure may be found in the Health Benefits TSD and the appendices to the BenMAP user manual (U.S. EPA, 2022a).

The baseline incidence rates for hospital admissions and emergency department visits reflect the revised rates first applied in the Revised Cross-State Air Pollution Rule Update (U.S. EPA, 2021a). In addition, we revised the baseline incidence rates for acute myocardial infarction. These revised rates are more recent than the rates they replace and more accurately represent the rates at which populations of different ages, and in different locations, visit the hospital and emergency department for air pollution-related illnesses. Lastly, these rates reflect unscheduled hospital admissions only, which represents a conservative assumption that most air pollution-related visits are likely to be unscheduled. If air pollution-related hospital admissions are scheduled, this assumption would underestimate these benefits.

4.3.5.3 Effect Coefficients

Our approach for selecting and parametrizing effect coefficients for the benefits analysis is described fully in the Health Benefits TSD. Because of the substantial economic value associated with estimated counts of $PM_{2.5}$-attributable deaths, we describe our rationale for selecting among long-term exposure epidemiologic studies below; a detailed description of all remaining endpoints may be found in the Health Benefits TSD.

A substantial body of published scientific literature documents the association between $PM_{2.5}$ concentrations and the risk of premature death (U.S. EPA, 2019a, 2022e). This body of literature reflects thousands of epidemiology, toxicology, and clinical studies. The PM ISA, completed as part of this review of the fPM standards and reviewed by the Clean Air Scientific Advisory Committee (CASAC) (U.S. EPA Science Advisory Board, 2022) concluded that there is a causal relationship between mortality and both long-term and short-term exposure to $PM_{2.5}$ based on the full body of scientific evidence. The size of the mortality effect estimates from epidemiologic studies, the serious nature of the effect itself, and the high monetary value ascribed to prolonging life make mortality risk reduction the most significant health endpoint quantified in this analysis.

EPA selects Hazard Ratios from cohort studies to estimate counts of PM-related premature death, following a systematic approach detailed in the Health Benefits TSD accompanying this RIA that is generally consistent with previous RIAs. Briefly, clinically significant epidemiologic studies of health endpoints for which ISAs report strong evidence are evaluated using established minimum and preferred criteria for identifying studies and hazard ratios best characterizing risk. Following this systematic approach led to the identification of three studies best characterizing the risk of premature death associated with long-term exposure to $PM_{2.5}$ in the U.S. (Pope et al., 2019; Turner et al., 2016; X Wu et al., 2020). The 2019 PM ISA (U.S. EPA, 2019a), the 2022 Supplement to the PM ISA (U.S. EPA, 2022e), and the 2022 PM Policy Assessment (U.S. EPA, 2022b) also identified these three studies as providing key evidence of the association between long-term $PM_{2.5}$ exposure and mortality. These studies used data from three U.S. cohorts: (1) an analysis of Medicare beneficiaries (Medicare); (2) the American Cancer Society (ACS); and (3) the National Health Interview Survey (NHIS). As premature mortality typically constitutes the vast majority of monetized benefits in a $PM_{2.5}$ benefits assessment, quantifying effects using risk estimates reported from multiple long-term exposure studies using different cohorts helps account for uncertainty in the estimated number of PM-related premature deaths. Below we summarize the three identified studies and hazard ratios and then describe our rationale for quantifying premature PM-attributable deaths using two of these studies.

Wu et al. (2020) evaluated the relationship between long-term $PM_{2.5}$ exposure and all-cause mortality in more than 68.5 million Medicare enrollees (over the age of 64), using Medicare claims data from 2000-2016 representing over 573 million person-years of follow up and over 27 million deaths. This cohort included over 20 percent of the U.S. population and was, at the time of publishing, the largest air pollution study cohort to date. The authors modeled $PM_{2.5}$ exposure at a 1 km grid resolution using a hybrid ensemble-based prediction model that combined three machine learning models and relied on satellite data, land-use information, weather variables, chemical transport model simulation outputs, and monitor data. Wu et al., 2020 fit five different statistical models: a Cox proportional hazards model, a Poisson regression model, and three causal inference approaches (GPS estimation, GPS matching, and GPS weighting). All five statistical approaches provided consistent results; we report the results of the Cox proportional hazards model here. The authors adjusted for numerous individual-level and community-level confounders, and sensitivity analyses suggest that the results are robust to unmeasured confounding bias. In a single-pollutant model, the coefficient and standard error for $PM_{2.5}$ are estimated from the hazard ratio (1.066) and 95 percent confidence interval (1.058-1.074) associated with a change in annual mean $PM_{2.5}$ exposure of 10.0 $\mu g/m^3$ (Wu et al., 2020, Table S3, Main analysis, 2000-2016 Cohort, Cox PH). We use a risk estimate from this study in place of the risk estimate from Di et al. (2017). These two epidemiologic studies share many attributes, including the Medicare cohort and statistical model used to characterize population exposure to $PM_{2.5}$. As compared to Di et al. (2017), Wu et al. (2020) includes a longer follow-up period and reflects more recent $PM_{2.5}$ concentrations.

Pope et al. (2019) examined the relationship between long-term $PM_{2.5}$ exposure and all-cause mortality in a cohort of 1,599,329 U.S. adults (aged 18-84 years) who were interviewed in the National Health Interview Surveys (NHIS) between 1986 and 2014 and linked to the National Death Index (NDI) through 2015. The authors also constructed a sub-cohort of 635,539 adults from the full cohort for whom body mass index (BMI) and smoking status data were available. The authors employed a hybrid modeling technique to estimate annual-average $PM_{2.5}$ concentrations derived from regulatory monitoring data and constructed in a universal kriging framework using geographic variables including land use, population, and satellite estimates. Pope et al. (2019) assigned annual-average $PM_{2.5}$ exposure from 1999-2015 to each individual by census tract and used complex (accounting for NHIS's sample design) and simple Cox proportional hazards models for the full cohort and the sub-cohort. We select the Hazard Ratio calculated using the complex model for the sub-cohort, which controls for individual-level covariates including age, sex, race-ethnicity, inflation-adjusted income, education level, marital status, rural versus urban, region, survey year, BMI, and smoking status. In a single-pollutant model, the coefficient and standard error for $PM_{2.5}$ are estimated from the hazard ratio (1.12) and 95 percent confidence interval (1.08-1.15) associated with a change in annual mean $PM_{2.5}$ exposure of 10.0 $\mu g/m^3$ (Pope et al., 2019, Table 2, Subcohort). This study exhibits two key strengths that makes it particularly well suited for a benefits analysis: (1) it includes a long follow-up period with recent (and thus relatively low) $PM_{2.5}$ concentrations; (2) the NHIS cohort is representative of the U.S. population, especially with respect to the distribution of individuals by race, ethnicity, income, and education.

EPA has historically used estimated Hazard Ratios from extended analyses of the ACS cohort to estimate PM-related risk of premature death Krewski (Krewski et al., 2009; Pope et al., 2002; Pope et al., 1995). A more recent ACS analysis, Turner et al. (2016):

- extended the follow-up period of the ACS CSP-II to 22 years (1982-2004),
- evaluated 669,046 participants over 12,662,562 person-years of follow up and 237,201 observed deaths, and

  applied a more advanced exposure estimation approach than had previously been used when analyzing the ACS cohort, combining the geostatistical Bayesian Maximum Entropy framework with national-level land use regression models.

The total mortality hazard ratio best estimating risk from these ACS cohort studies was based on a random-effects Cox proportional hazard model incorporating multiple individual and ecological covariates (relative risk =1.06, 95 percent confidence intervals 1.04–1.08 per 10 $\mu g/m^3$ increase in $PM_{2.5}$) from Turner et al. (2016). The relative risk estimate is identical to a risk estimate drawn from earlier ACS analysis of all-cause long-term exposure $PM_{2.5}$-attributable mortality (Krewski et al., 2009). However, as the ACS hazard ratio is quite similar to the Medicare estimate of (1.066, 1.058-1.074), especially when considering the broader age range (greater than 29 versus greater than 64), only Wu et al. (2020) and Pope et al. (2019) are included in the main benefits assessments, with Wu et al. (2020) representing results from both the Medicare and ACS cohorts.

4.3.6 Quantifying Cases of Ozone-Attributable Premature Death

Mortality risk reductions account for the majority of monetized ozone-related and $PM_{2.5}$-related benefits. For this reason, this subsection and the following provide a brief background of the scientific assessments that underly the quantification of these mortality risks and identifies the risk studies used to quantify them in this RIA, for ozone and $PM_{2.5}$ respectively. As noted above, U.S. EPA (2023a) describes fully the Agency's approach for quantifying the number and value of ozone and $PM_{2.5}$ air pollution-related impacts, including additional discussion of how the Agency selected the risk studies used to quantify them in this RIA. The Health Benefits TSD also includes additional discussion of the assessments that support quantification of these mortality risk than provide here.

In 2008, the National Academies of Science issued a series of recommendations to EPA regarding the procedure for quantifying and valuing ozone-related mortality due to short-term exposures (National Research Council, 2008). 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 [National Mortality and Morbidity Air Pollution Studies (NMMAPS)] …studies without exclusion of the meta-analyses" (National Research Council, 2008). Prior to the 2015 Ozone NAAQS RIA, the Agency estimated ozone-attributable premature deaths using an NMMAPS-based analysis of total mortality (Bell et al., 2004), two multi-city studies of cardiopulmonary and total mortality (Huang et al., 2005; Schwartz, 2005), and effect estimates from three meta-analyses of non-accidental mortality (Bell et al., 2005; Ito et al., 2005; Levy et al., 2005). Beginning with the 2015 Ozone NAAQS RIA, the Agency began quantifying ozone-attributable premature deaths using two newer multi-city studies of non-accidental mortality (R. L. Smith et al., 2009; Zanobetti and Schwartz, 2008) and one long-term cohort study of respiratory mortality (Jerrett et al. 2009).

EPA quantifies and monetizes effects the Integrated Science Assessment (ISA) identifies as having either a causal or likely-to-be-causal relationship with the pollutant. Relative to the 2015 ISA, the 2020 ISA for Ozone reclassified the casual relationship between short-term ozone exposure and total mortality, changing it from "likely to be causal" to "suggestive of, but not sufficient to infer, a causal relationship." The 2020 Ozone ISA separately classified short-term ozone exposure and respiratory outcomes as being "causal" and long-term exposure as being "likely to be causal." When determining whether there existed a causal relationship between short- or long-term ozone exposure and respiratory effects, EPA evaluated the evidence for both morbidity and mortality effects. The ISA identified evidence in the epidemiologic literature of an association between ozone exposure and respiratory mortality, finding that the evidence was not entirely consistent and there remained uncertainties in the evidence base.

EPA continues to quantify premature respiratory mortality attributable to both short- and long-term exposure to ozone because doing so is consistent with: (1) the evaluation of causality noted above; and (2) EPA's approach for selecting and quantifying endpoints described in the Technical Support Document (TSD) "Estimating $PM_{2.5}$- and Ozone-Attributable Health Benefits," which was recently reviewed by the U.S. EPA Science Advisory Board (U.S. EPA, 2023; U.S. EPA-SAB 2024).

We estimate counts of ozone-attributable respiratory death from short-term exposures a pooled risk estimate calculated using parameters from Zanobetti and Schwartz (2008) and Katsouyanni et al. (2009). Consistent with the RIA for the Final Revised CSAPR Update (U.S. EPA, 2021a), we use two estimates of ozone-attributable respiratory deaths from short-term exposures are estimated using the risk estimate parameters from Zanobetti and Schwartz (2008) and Katsouyanni et al. (2009). Ozone-attributable respiratory deaths from long-term exposures are estimated using Turner et al. (2016). Due to time and resource limitations, we were unable to reflect the warm season defined by Zanobetti and Schwartz (2008) as June-August. Instead, we apply this risk estimate to our standard warm season of May-September.

4.3.7 Quantifying Cases of $PM_{2.5}$-Attributable Premature Death

When quantifying PM-attributable cases of adult mortality, we use the effect coefficients from two epidemiology studies examining two large population cohorts: the American Cancer Society cohort (Turner et al., 2016) and the Medicare cohort (Di et al., 2017). The 2019 PM ISA indicates that the ACS and Medicare cohorts provide strong evidence of an association between long-term $PM_{2.5}$ exposure and premature mortality with support from additional cohort studies. There are distinct attributes of both the ACS and Medicare cohort studies that make them well-suited to being used in a PM benefits assessment and so here we present $PM_{2.5}$ related effects derived using relative risk estimates from both cohorts.

The PM ISA, which was reviewed by the Clean Air Scientific Advisory Committee of EPA's Science Advisory Board (U.S. EPA Science Advisory Board, 2022), 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 relationship. The 2019 PM ISA, which informed the setting of the 2020 PM NAAQS, reviewed available studies that examined the potential for a population-level threshold to exist in the concentration-response relationship. Based on such studies, the ISA concluded that the evidence supports the use of a "no-threshold" model and that "little evidence was observed to suggest that a threshold exists" (U.S. EPA, 2009a). Consistent with this evidence, the Agency historically has estimated health impacts above and below the prevailing NAAQS (U.S. EPA, 2019b, 2021a, 2022c).

4.3.8 Characterizing Uncertainty in the Estimated Benefits

Like other complex analyses using estimated parameters and inputs from numerous models, there are sources of uncertainty. The Health Benefits TSD details our approach to characterizing uncertainty in both quantitative and qualitative terms (U.S. EPA, 2023a). The Health Benefits TSD describes the sources of uncertainty associated with key input parameters including emissions 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 benefits, and assumptions regarding the future state of the country (i.e., regulations, technology, and human behavior). Each of these inputs is uncertain and affects the size and distribution of the estimated benefits. When the uncertainties from each stage of the analysis are compounded, even small uncertainties can have large effects on the total quantified benefits.

To characterize uncertainty and variability into this assessment, we incorporate three quantitative analyses described below and in greater detail within the Health Benefits TSD (Section 7.1):

1. A Monte Carlo assessment that accounts for random sampling error and between study variability in the epidemiological and economic valuation studies;
2. The quantification of PM-related mortality using alternative $PM_{2.5}$ mortality effect estimates drawn from two long-term cohort studies; and
3. Presentation of 95th percentile confidence interval around each risk estimate.

Quantitative characterization of other sources of $PM_{2.5}$ uncertainties are discussed only in Section 7.1 of the Health Benefits TSD:

1. For adult all-cause mortality:

    a. The distributions of air quality concentrations experienced by the original cohort population (Health Benefits TSD Section 7.1.2.1);
    b. Methods of estimating and assigning exposures in epidemiologic studies (Health Benefits TSD Section 7.1.2.2);
    c. Confounding by ozone (Health Benefits TSD Section 7.1.2.3); and
    d. The statistical technique used to generate hazard ratios in the epidemiologic study (Health Benefits TSD Section 7.1.2.4).
2. Plausible alternative risk estimates for asthma onset in children (TSD Section 7.1.3), cardiovascular hospital admissions (Health Benefits TSD Section 7.1.4,), and respiratory hospital admissions (Health Benefits TSD Section 7.1.5);
3. Effect modification of $PM_{2.5}$-attributable health effects in at-risk populations (Health Benefits TSD Section 7.1.6).

Quantitative consideration of baseline incidence rates and economic valuation estimates are provided in Section 7.3 and 7.4 of the Health Benefits TSD, respectively. Qualitative discussions of various sources of uncertainty can be found in Section 7.5 of the Health Benefits TSD.

4.3.8.1 Monte Carlo Assessment

Similar to other recent RIAs, we used Monte Carlo methods for characterizing random sampling error associated with the concentration response functions from epidemiological studies and random effects modeling to characterize both sampling error and variability across the economic valuation functions. The Monte Carlo simulation in the BenMAP-CE software randomly samples from a distribution of incidence and valuation estimates to characterize the effects of uncertainty on output variables. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and monetized benefits. The reported standard errors in the epidemiological studies determined the distributions for individual effect estimates for endpoints estimated using a single study. For endpoints estimated using a pooled estimate of multiple studies, the confidence intervals reflect both the standard errors and the variance across studies. The confidence intervals around the monetized benefits incorporate the epidemiology standard errors as well as the distribution of the valuation function. 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.

4.3.8.2 Sources of Uncertainty Treated Qualitatively

Although we strive to incorporate as many quantitative assessments of uncertainty as possible, there are several aspects we are only able to address qualitatively. These attributes are summarized below and described more fully in the Health Benefits TSD.

Key assumptions underlying the estimates for premature mortality, which account for over 98 percent of the total monetized benefits in this analysis, include the following:

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, which was reviewed by CASAC, concluded that "across exposure durations and health effects categories … the evidence does not indicate that any one source or component is consistently more strongly related with health effects than $PM_{2.5}$ mass" (U.S. EPA Science Advisory Board, 2022).
2. We assume that the health impact function for fine particles is log-linear down to the lowest air quality levels modeled in this analysis. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5}$, including both regions that are in attainment with the fine particle standard and those that do not meet the standard down to the lowest modeled concentrations. The PM ISA concluded that "the majority of evidence continues to indicate a linear, no-threshold concentration-response relationship for long-term exposure to $PM_{2.5}$ and total (nonaccidental) mortality" (U.S. EPA Science Advisory Board, 2022).
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 board (U.S. EPA Science Advisory Board, 2004), which affects the valuation of mortality benefits at different discount rates. Similarly, we assume there is a cessation lag between the change in PM exposures and both the development and diagnosis of lung cancer.

4.3.9 Estimated Number and Economic Value of Health Benefits

To directly compare benefits estimates associated with a rulemaking to cost estimates, the number of instances of each air pollution-attributable health impact must be converted to a monetary value. This requires a valuation estimate for each unique health endpoint, and potentially also discounting if the benefits are expected to accrue over more than a single year, as recommended by the Guidelines for Preparing Economic Analyses (U.S. EPA, 2014). Below we report the estimated number of reduced premature deaths and illnesses in each year relative to the baseline along with the 95 percent confidence interval (Table 4-2 or ozone-related health impacts and Table 4-3 for $PM_{2.5}$-related impacts). The number of reduced estimated deaths and illnesses from the final are calculated from the sum of individual reduced mortality and illness risk across the population.

Table 4-2 Estimated Avoided Ozone-Related Premature Respiratory Mortalities and Illnesses for the Final Rule for 2028, 2030, and 2035 (95 percent confidence interval) [a]

		2028	2030	2035[g]
Avoided premature respiratory mortalities				
Long-term exposure	Turner et al. (2016)[b]	0.37 (0.26 to 0.48)	0.019 (0.013 to 0.025)	-0.07 (-0.091 to -0.049)
Short-term exposure	Katsouyanni et al. (2009)[b,c] and Zanobetti et al. (2008)[c] pooled	0.017 (0.0068 to 0.027)	0.0009 (0.0004 to 0.0014)	-0.0032 (-0.005 to -0.0013)
Morbidity effects				
Long-term exposure	Asthma onset[d]	2.3 (2 to 2.6)	0.25 (0.22 to 0.29)	-0.9 (-1.0 to -0.78)
	Allergic rhinitis symptoms[f]	14 (7.1 to 20)	1.5 (0.79 to 2.2)	-5.1 (-7.4 to -2.7)
Short-term exposure	Hospital admissions—respiratory[c]	0.055 (-0.014 to 0.12)	0.0041 (-0.0011 to 0.009)	-0.0098 (-0.022 to 0.0026)
	ED visits—respiratory[e]	0.62 (0.17 to 1.31)	0.58 (0.016 to 0.12)	-0.14 (-0.3 to -0.039)
	Asthma symptoms	440 (-54 to 920)	48 (-5.9 to 100)	-160 (-340 to 20)
	Minor restricted-activity days[c,e]	190 (76 to 300)	21 (8.2 to 32)	-64 (-100 to -26)
	School absence days	160 (-22 to 330)	17 (-2.5 to 37)	-58 (-120 to 8.2)

[a] Values rounded to two significant figures.

[b] Applied risk estimate derived from April-September exposures to estimates of ozone across the May-September warm season.

[c] Converted ozone risk estimate metric from MDA1 to MDA8.

[d] Applied risk estimate derived from June-August exposures to estimates of ozone across the May-September warm season.

[e] Applied risk estimate derived from full year exposures to estimates of ozone across the May-September warm season.

[f] Converted ozone risk estimate metric from DA24 to MDA8.

[g] In 2035, the IPM model projects a small projected increase in NOX emissions results from very small, modeled changes in fossil dispatch and coal use relative to the baseline. As shown in Figure 8-8, while there are small predicted ozone decreases from the final rule compared to the baseline evident in North Dakota in 2028 and Montana in 2035, there are also small predicted ozone increases evident near the border of Arizona and New Mexico in 2035. These small increases result in the very small negative health impacts presented in this table.

Table 4-3 Estimated Avoided $PM_{2.5}$-Related Premature Mortalities and Illnesses for the Final Rule in 2028, 2030, and 2035 (95 percent confidence interval)

Avoided Mortality	**2028**	**2030**	**2035**
(Pope et al., 2019) (adult mortality ages 18-99 years)	7.2 (5.2 to 9.2)	2.7 (1.9 to 3.4)	1.7 (1.2 to 2.1)
(X. Wu et al., 2020) (adult mortality ages 65-99 years)	3.4 (3 to 3.8)	1.3 (1.1 to 1.4)	0.84 (0.74 to 0.94)
(Woodruff et al., 2008) (infant mortality)	0.0087 (-0.0055 to 0.022)	0.0026 (-0.0016 to 0.0066)	0.0013 (-0.00083 to 0.0034)
Avoided Morbidity	**2028**	**2030**	**2035**
Hospital admissions—cardiovascular (age > 18)	0.5 (0.37 to 0.64)	0.19 (0.13 to 0.24)	0.12 (0.084 to 0.15)
Hospital admissions—respiratory	0.73 (0.25 to 1.2)	0.23 (0.076 to 0.37)	0.12 (0.038 to 0.20)
ED visits--cardiovascular	1.1 (-0.4 to 2.5)	0.37 (-0.14 to 0.87)	0.23 (-0.088 to 0.53)
ED visits—respiratory	2 (0.4 to 4.3)	0.72 (0.14 to 1.5)	0.41 (0.081 to 0.86)
Acute Myocardial Infarction	0.12 (0.07 to 0.17)	0.042 (0.024 to 0.059)	0.025 (0.015 to 0.036)
Cardiac arrest	0.053 (-0.022 to 0.12)	0.019 (-0.0076 to 0.043)	0.011 (-0.0045 to 0.25)
Hospital admissions--Alzheimer's Disease	2 (1.5 to 2.5)	0.6 (0.44 to 0.74)	0.33 (0.24 to 0.41)
Hospital admissions--Parkinson's Disease	0.23 (0.12 to 0.34)	0.087 (0.044 to 0.13)	0.054 (0.027 to 0.08)
Stroke	0.21 (0.0055 to 0.36)	0.077 (0.02 to 0.13)	0.047 (0.012 to 0.081)
Lung cancer	0.24 (0.072 to 0.4)	0.087 (0.026 to 0.15)	0.055 (0.017 to 0.092)
Hay Fever/Rhinitis	52 (13 to 91)	17 (4.2 to 30)	9.7 (2.3 to 17)
Asthma Onset	8.1 (7.8 to 8.4)	2.7 (2.5 to 2.8)	1.4 (1.4 to 1.5)
Asthma symptoms – Albuterol use	1,500 (-743 to 3,700)	510 (-250 to 1,200)	290 (-140 to 690)
Lost work days	390 (330 to 450)	130 (110 to 150)	73 (62 to 84)
Minor restricted-activity days	2,300 (1,900 to 2,700)	780 (640 to 930)	430 (350 to 510)

Note: Values rounded to two significant figures.

To directly compare benefits estimates associated with a rulemaking to cost estimates, the number of instances of each air pollution-attributable health impact must be converted to a monetary value. This requires a valuation estimate for each unique health endpoint, and potentially also discounting if the benefits are expected to accrue over more than a single year, as recommended by the U.S. EPA (2014). Table 4-4 reports the estimated economic value of avoided premature deaths and illness in each year relative to the baseline along with the 95 percent confidence interval. Table 4-5 through Table 4-7 presents the stream of health benefits from 2028 through 2037 for the final rule using the monetized sums of long-term ozone and $PM_{2.5}$ mortality and morbidity impacts discounted at 2, 3, and 7 percent, respectively.[57] Note the benefits of the less stringent regulatory alternative are described qualitatively. As a result, there are no quantified benefits associated with this regulatory option.

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[57] EPA continues to refine its approach for estimating and reporting PM-related effects at lower concentrations. The Agency acknowledges the additional uncertainty associated with effects estimated at these lower levels and seeks to develop quantitative approaches for reflecting this uncertainty in the estimated PM benefits.

Table 4-4 Estimated Discounted Economic Value of Avoided Ozone and $PM_{2.5}$-Attributable Premature Mortality and Illness for the Final Rule 2028, 2030, and 2035 (95 percent confidence interval; millions of 2019 dollars)[a,b,c]

Disc. Rate	Pollutant	2028			2030			2035		
2%	Ozone Benefits	$1.3	*and*	$5.2	$0.13	*and*	$0.34	-$1.2	*and*	-$0.48
	$PM_{2.5}$ Benefits	$41	*and*	$82	$15	*and*	$30	$10	*and*	$19
	Ozone plus $PM_{2.5}$ Benefits	$42	*and*	$87	$15	*and*	$30	$9.50	*and*	$18
3%	Ozone Benefits	$0.71 ($0.34 to $1.3)	*and*	$4 ($0.66 to $11)	$0.066 ($0.36 to $0.11)	*and*	$0.26 ($0.053 to $0.63)	$-0.96 ($-2.3 to $-0.19)	*and*	$-0.24 ($-0.38 to -$0.13)
	$PM_{2.5}$ Benefits	$38 ($5 to $97)	*and*	$78 ($8.4 to $210)	$14 ($1.8 to $37)	*and*	$29 ($3.1 to $76)	$9.5 ($1.1 to $24)	*and*	$19 ($1.9 to $49)
	Ozone plus $PM_{2.5}$ Benefits	$39 ($5.3 to $98)	*and*	$82 ($9.1 to $220)	$14 ($2.4 to 37)	*and*	$29 ($3.2 to $77)	$9.3 ($0.72 to $24)	*and*	$18 ($-0.4 to $49)
7%	Ozone Benefits	$0.53 ($0.18 to $1.1)	*and*	$3.8 ($0.48 to $9.9)	$0.047 ($0.019 to $0.084)	*and*	$0.22 ($0.034 to $0.55)	$-0.17 ($-0.3 to $-0.068)	*and*	$-0.81 ($-2 to $-0.13)
	$PM_{2.5}$ Benefits	$34 ($4.1 to $86)	*and*	$70 ($7.2 to $180)	$13 ($1.5 to $33)	*and*	$26 ($2.6 to $69)	$8.5 ($0.95 to $22)	*and*	$17 ($1.7 to $44)
	Ozone plus $PM_{2.5}$ Benefits	$35 ($4.3 to $87)	*and*	$7 ($7.7 to $190)	$13 ($1.5 to $33)	*and*	$26 ($2.6 to $70)	$8.3 ($0.65 to $22)	*and*	$16 ($-0.3 to $44)

[a] Values rounded to two significant figures. The two benefits estimates are separated by the word "and" to signify that they are two separate estimates. The estimates do not represent lower- and upper-bound estimates and should not be summed.

[b] We estimated changes in NO_X for the ozone season and changes in $PM_{2.5}$ and $PM_{2.5}$ precursors in 2028, 2030, and 2035.

[c] EPA is unable to provide confidence intervals for 2 percent-based estimates currently.

[d] Sum of ozone mortality estimated using the pooled short-term ozone exposure risk estimate and the Wu et al. (2020) long-term $PM_{2.5}$ exposure mortality risk estimate.

[e] Sum of the Turner et al. (2016) long-term ozone exposure risk estimate and the Pope et al. (2019) long-term $PM_{2.5}$ exposure mortality risk estimate.

Table 4-5 Stream of Estimated Human Health Benefits from 2028 through 2037: Monetized Benefits Quantified as Sum of Long-Term Ozone Mortality and Long-Term $PM_{2.5}$ Mortality (discounted at 2 percent to 2023; millions of 2019 dollars)[a]

Year		Under the Final Rule	
2028[b]	\$38	and	\$79
2029	\$38	and	\$79
2030[b]	\$13	and	\$27
2031	\$14	and	\$27
2032	\$7.4	and	\$14
2033	\$7.5	and	\$14
2034	\$7.5	and	\$14
2035[b]	\$7.6	and	\$14
2036	\$7.6	and	\$14
2037	\$7.6	and	\$14
PV	**\$150**	**and**	**\$300**
EAV	**\$17**	**and**	**\$33**

[a] Benefits for all other years were extrapolated from years with model-based air quality estimates. Benefits calculated as value of avoided: $PM_{2.5}$-attributable deaths quantified using a concentration-response relationship from Wu et al. (2020) and Pope et al. (2019); Ozone-attributable deaths quantified using a concentration-response relationship from the Turner et al. (2017); and $PM_{2.5}$ and ozone-related morbidity effects. The two benefits estimates are separated by the word "and" to signify that they are two separate estimates. The estimates do not represent lower- and upper-bound estimates and should not be summed.

[b] Analysis year in which air quality models were run.

Table 4-6 Stream of Estimated Human Health Benefits from 2028 through 2037: Monetized Benefits Quantified as Sum of Long-Term Ozone Mortality and Long-Term $PM_{2.5}$ Mortality (discounted at 3 percent to 2023; millions of 2019 dollars)[a]

Year	Under the Final Rule		
2028[b]	$34	and	$71
2029	$33	and	$71
2030[b]	$12	and	$24
2031	$12	and	$24
2032	$6.6	and	$13
2033	$6.6	and	$13
2034	$6.5	and	$12
2035[b]	$6.5	and	$12
2036	$6.5	and	$12
2037	$6.4	and	$12
PV	**$130**	**and**	**$260**
EAV	**$15**	**and**	**$31**

[a] Benefits for all other years were extrapolated from years with model-based air quality estimates. Benefits calculated as value of avoided: $PM_{2.5}$-attributable deaths quantified using a concentration-response relationship from Wu et al. (2020) and Pope et al. (2019); Ozone-attributable deaths quantified using a concentration-response relationship from the Turner et al. (2017); and $PM_{2.5}$ and ozone-related morbidity effects. The two benefits estimates are separated by the word "and" to signify that they are two separate estimates. The estimates do not represent lower- and upper-bound estimates and should not be summed.

[b] Analysis year in which air quality models were run.

Table 4-7 Stream of Estimated Human Health Benefits from 2028 through 2037: Monetized Benefits Quantified as Sum of Long-Term Ozone Mortality and Long-Term $PM_{2.5}$ Mortality (discounted at 7 percent to 2023; millions of 2019 dollars)[a]

Year	Under the Final Rule		
2028[b]	$25	and	$52
2029	$24	and	$50
2030[b]	$8.0	and	$16
2031	$7.7	and	$16
2032	$4.2	and	$8.0
2033	$4.0	and	$7.7
2034	$3.9	and	$7.3
2035[b]	$3.7	and	$7.0
2036	$3.5	and	$6.7
2037	$3.4	and	$6.4
PV	**$86**	**and**	**$180**
EAV	**$12**	**and**	**$25**

[a] Benefits for all other years were extrapolated from years with model-based air quality estimates. Benefits calculated as value of avoided: $PM_{2.5}$-attributable deaths quantified using a concentration-response relationship from Wu et al. (2020) and Pope et al. (2019); Ozone-attributable deaths quantified using a concentration-response relationship from the Turner et al. (2017); and $PM_{2.5}$ and ozone-related morbidity effects. The two benefits estimates are separated by the word "and" to signify that they are two separate estimates. The estimates do not represent lower- and upper-bound estimates and should not be summed.

[b] Analysis year in which air quality models were run.

This analysis uses several recent improvements in health endpoint valuation. School loss days now account for lost human capital formation, as was discussed in the Health Benefits TSD which was reviewed by the EPA Scientific Advisory Board's Review of BenMAP and Benefits Methods. We include new estimates of the cost asthma onset and stroke beyond those described in the Health Benefits TSD.

The new valuation estimate for school loss days is described in the Health Benefits TSD in Section 5.3.8. We include two costs of school loss days: caregiver costs and loss of learning. We calculate each separately and then sum. Caregiver costs are valued at their employers' average cost for employed caregivers. For unemployed caregivers, the opportunity cost of their time is calculated as the average take-home pay. The loss of learning is calculated based on the impact of absences on learning multiplied by the impact of school learning on adult earnings. The loss of learning estimate is currently only available for middle and high school students. The two costs are summed.

The caregiver costs assume that an adult caregiver stays home with the child and loses any wage income they would have earned that day. For working caregivers, we follow EPA guidance and value their time at the average wage including fringe benefits and overhead costs. The average daily wage in 2021 was $195 (2015 dollars, assumed to be the average weekly wage divided by 5),[58] which yields an average daily labor cost of $340 for employed parents after applying average multipliers of 1.46 for fringe benefits and 1.2 for overhead. For nonworking caregivers, we assume that the opportunity cost of time is the average after-tax earnings. We estimate the income tax rate for a median household to be 7 percent, yielding net earnings of $195 multiplied by 0.93 or $181 (2015 dollars). The income tax rate of 7 percent is the percentage difference in median post-tax income and median income from Tables A1 and C1 in Shrider et al. (2021).

The probability that a parent is working is measured with the employment population ratio among people with their own children under 18 and is 77.2 percent.[59] Combining the cost of working and nonworking caregivers yields a caregiver cost of $305 per school loss day.

To measure the loss of learning, we update the Liu et al. (2021) estimate. Liu et al. (2021) estimated the impact of a school absence on learnings as measured by an end-of-course test score. We multiply by an estimate of the impact of learning as measured by end-of-course test scores on adult income from Chetty et al. (2014). This approach yields an estimated learning loss of $2,842 per school absence (discounted at 2 percent), $2,230 per school absence (discounted at 3 percent) and $975 per school absence (discounted at 7 percent).

We updated the Chetty et al. (2014) estimate to use 2010 income and to estimate lifetime incomes discounted at 3 percent and 7 percent. Liu et al. (2021) estimate that a school absence leads to a $1,200 reduction in lifetime earnings, based on the Chetty et al. (2014) estimate that lifetime earnings are $522,000 (2010 dollars). We use 2010 ACS data from IPUMS to calculate expected lifetime earnings of $1,137,732 (discounting at 2 percent), $892,579 (discounting at 3 percent) and $390,393 (discounting at 7 percent). We then multiply the Liu et al. (2021) estimate of $1,200 by ($1,137,732 divided by $522,000) and ($892,579 divided by $522,000) and

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[58] U.S, Bureau of Labor Statistics (2022), series Employment, Hours, and Earnings from the Current Employment Statistics (Series ID CES0500000011).

[59] US Bureau of Labor Statistics Employment Characteristics of Families, 2021, Table 5.

($390,393 divided by $522,000) and convert from 2010 dollars to 2015 dollars based on the Consumer Price Index for All Urban Consumers.

We use caregiver costs for preschool and elementary school children and the sum of caregiver costs and loss of learning for middle school and high school students. We calculate that 31 percent of children under 18 are middle school and high school ages 13-18, assuming each bin is distributed equally, so the combined average effect is $1,186 ($305 plus $2,842 multiplied by 0.31) with 2 percent discounting, $1,000 ($305 plus $2,230 multiplied by 0.31) with 3 percent discounting, and $610 ($305 plus $975 multiplied by 0.31) with 7 percent discounting in 2015 dollars (U.S. Census Bureau, 2010).[60]

We include a new estimate of the cost of illness of asthma onset based on Maniloff and Fann (2023). These estimates are $181,249 with a 2 percent discount rate, $146,370 with a 3 percent discount rate, and $76,629 with a 7 percent discount rate (2015 dollars). We also include a new estimate of the cost of illness of stroke onset based on Maniloff and Fann (2023).These estimates are $158,763 with a 2 percent discount rate, $150,675 with a 3 percent discount rate, and $123,984 with a 7 percent discount rate (2015 dollars).

4.3.10 Additional Unquantified Benefits

Data, time, and resource limitations prevented EPA from quantifying the estimated health impacts or monetizing estimated benefits associated with direct exposure to NO_2 and SO_2, independent of the role NO_2 and SO_2 play as precursors to $PM_{2.5}$ and ozone, ecosystem effects, and visibility impairment due to the absence of air quality modeling data for these pollutants in this analysis. While all health benefits and welfare benefits were not able to be quantified, it does not imply that there are not additional benefits associated with reductions in exposures to ozone, $PM_{2.5}$, NO_2 or SO_2. Criteria pollutants from U.S. EGUs can also be transported downwind into foreign countries, in particular Canada and Mexico. Therefore, reduced criteria pollutants from U.S. EGUs can lead to public health and welfare benefits in foreign countries. EPA is currently unable to quantify or monetize these effects.

The EPA is also unable to quantify and monetize the incremental potential benefits of requiring facilities to utilize CEMS rather than continuing to allow the use of quarterly testing,

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[60] U.S. Census Bureau, Age and Sex Composition in the United States: 2010, Table 1, *https://www.census.gov/data/tables/2010/demo/age-and-sex/2010-age-sex-composition.html.*

but the requirement has been considered qualitatively. The continuous monitoring of fPM required in this rule is also likely to provide several additional benefits to the public which are not quantified in this rule, including greater certainty, accuracy, transparency, and granularity in fPM emissions information than exists today.

Table 4-8 Additional Unquantified Benefit Categories

Category	Effect	Effect Quantified	Effect Monetized	More Information
Improved Human Health				
Reduced incidence of morbidity from exposure to NO_2	Asthma hospital admissions	—	—	NO_2 ISA[1]
	Chronic lung disease hospital admissions	—	—	NO_2 ISA[1]
	Respiratory emergency department visits	—	—	NO_2 ISA[1]
	Asthma exacerbation	—	—	NO_2 ISA[1]
	Acute respiratory symptoms	—	—	NO_2 ISA[1]
	Premature mortality	—	—	NO_2 ISA[1,2,3]
	Other respiratory effects (e.g., airway hyperresponsiveness and inflammation, lung function, other ages, and populations)	—	—	NO_2 ISA[2,3]
Improved Environment				
Reduced visibility impairment	Visibility in Class 1 areas	—	—	PM ISA[1]
	Visibility in residential areas	—	—	PM ISA[1]
Reduced effects on materials	Household soiling	—	—	PM ISA[1,2]
	Materials damage (e.g., corrosion, increased wear)	—	—	PM ISA[2]
Reduced effects from PM deposition (metals and organics)	Effects on individual organisms and ecosystems	—	—	PM ISA[2]
Reduced vegetation and ecosystem effects from exposure to ozone	Visible foliar injury on vegetation	—	—	Ozone ISA[1]
	Reduced vegetation growth and reproduction	—	—	Ozone ISA[1]
	Yield and quality of commercial forest products and crops	—	—	Ozone ISA[1]
	Damage to urban ornamental plants	—	—	Ozone ISA[2]
	Carbon sequestration in terrestrial ecosystems	—	—	Ozone ISA[1]
	Recreational demand associated with forest aesthetics	—	—	Ozone ISA[2]
	Other non-use effects			Ozone ISA[2]

Table 4-8 Additional Unquantified Benefit Categories

Category	Effect	Effect Quantified	Effect Monetized	More Information
	Ecosystem functions (e.g., water cycling, biogeochemical cycles, net primary productivity, leaf-gas exchange, community composition)	—	—	Ozone ISA[2]
Reduced effects from acid deposition	Recreational fishing	—	—	NO_X SO_X ISA[1]
	Tree mortality and decline	—	—	NO_X SO_X ISA[2]
	Commercial fishing and forestry effects	—	—	NO_X SO_X ISA[2]
	Recreational demand in terrestrial and aquatic ecosystems	—	—	NO_X SO_X ISA[2]
	Other non-use effects			NO_X SO_X ISA[2]
	Ecosystem functions (e.g., biogeochemical cycles)	—	—	NO_X SO_X ISA[2]
Reduced effects from nutrient enrichment from deposition.	Species composition and biodiversity in terrestrial and estuarine ecosystems	—	—	NO_X SO_X ISA[2]
	Coastal eutrophication	—	—	NO_X SO_X ISA[2]
	Recreational demand in terrestrial and estuarine ecosystems	—	—	NO_X SO_X ISA[2]
	Other non-use effects			NO_X SO_X ISA[2]
	Ecosystem functions (e.g., biogeochemical cycles, fire regulation)	—	—	NO_X SO_X ISA[2]
Reduced vegetation effects from ambient exposure to SO_2 and NO_x	Injury to vegetation from SO_2 exposure	—	—	NO_X SO_X ISA[2]
	Injury to vegetation from NO_x exposure	—	—	NO_X SO_X ISA[2]

[1] We assess these benefits qualitatively due to data and resource limitations for this RIA.

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

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

4.3.10.1 NO_2 Health Benefits

In addition to being a precursor to $PM_{2.5}$ and ozone, NO_X emissions are also linked to a variety of adverse health effects associated with direct exposure. We were unable to estimate the health benefits associated with reduced NO_2 exposure in this analysis. Following a comprehensive review of health evidence from epidemiologic and laboratory studies, the ISA for Oxides of Nitrogen —Health Criteria (NO_X ISA) concluded that there is a likely causal relationship between respiratory health effects and short-term exposure to NO_2 (U.S. EPA, 2016). These epidemiologic and experimental studies encompass a number of endpoints including emergency department visits and hospitalizations, respiratory symptoms, airway hyperresponsiveness, airway inflammation, and lung function. The NO_X ISA also concluded that the relationship between short-term NO_2 exposure and premature mortality was “suggestive but not sufficient to infer a causal relationship,” because it is difficult to attribute the mortality risk effects to NO_2 alone. Although the NO_X ISA stated that studies consistently reported a relationship between NO_2 exposure and mortality, the effect was generally smaller than that for other pollutants such as PM.

4.3.10.2 SO_2 Health Benefits

In addition to being a precursor to $PM_{2.5}$, SO_2 emissions are also linked to a variety of adverse health effects associated with direct exposure. We were unable to estimate the health benefits associated with reduced SO_2 in this analysis. Therefore, this analysis only quantifies and monetizes the $PM_{2.5}$ benefits associated with the reductions in SO_2 emissions. Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the ISA for Oxides of Sulfur—Health Criteria (SO_2 ISA) concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2 sulfur (U.S. EPA, 2017). The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. Asthmatics are more sensitive to the effects of SO_2, likely resulting from preexisting inflammation associated with this disease. A clear concentration-response relationship has been demonstrated in laboratory studies following exposures to SO_2 at concentrations between 20 and 100 parts per billion (ppb), both in terms of increasing severity of effect and percentage of asthmatics adversely affected. Based on our review of this information, we identified three short-term morbidity endpoints that the SO_2 ISA identified as a “causal relationship”: asthma exacerbation, respiratory-related emergency department visits, and respiratory-related hospitalizations. The differing evidence and associated strength of the evidence for these different effects is described in detail in the SO_2 ISA. The SO_2 ISA also concluded that the relationship between short-term SO_2 exposure and premature mortality was “suggestive of a causal relationship” because it is difficult to attribute the mortality risk effects to SO_2 alone. Although the SO_2 ISA stated that studies are generally consistent in reporting a relationship between SO_2 exposure and mortality, there was a lack of robustness of the observed associations to adjustment for other pollutants.

4.3.10.3 Ozone Welfare Benefits

Exposure to ozone has been associated with a wide array of vegetation and ecosystem effects in the published literature ecological (U.S. EPA, 2020c). Sensitivity to ozone is highly variable across species, with over 65 plant species identified as “ozone-sensitive,” many of which occur in state and national parks and forests. These effects include those that damage or impair the intended use of the plant or ecosystem. Such effects can include reduced growth and/or biomass production in sensitive plant species, including forest trees, reduced yield and quality of crops, visible foliar injury, species composition shift, and changes in ecosystems and associated ecosystem services. See Section F of the *Ozone Transport Policy Analysis Proposed Rule TSD* for a summary of an assessment of risk of ozone-related growth impacts on selected forest tree species (U.S. EPA, 2022f).

4.3.10.4 NO_2 and SO_2 Welfare Benefits

As described in the ISAs for Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter Ecological Criteria (U.S. EPA, 2020c), NO_X and SO_2 emissions also contribute to a variety of adverse welfare effects, including those associated with acidic deposition, visibility impairment, and nutrient enrichment. Deposition of nitrogen and sulfur causes acidification, which can cause a loss of biodiversity of fishes, zooplankton, and macro invertebrates in aquatic ecosystems, as well as a decline in sensitive tree species, such as red spruce (*Picea rubens*) and sugar maple (Acer saccharum) in terrestrial ecosystems. In the northeastern U.S., the surface waters affected by acidification are a source of food for some recreational and subsistence fishermen and for other consumers and support several cultural services, including aesthetic and educational services and recreational fishing. Biological effects of acidification in terrestrial ecosystems are generally linked to aluminum toxicity, which can cause reduced root growth, restricting the ability of the plant to take up water and nutrients. These direct effects can, in turn, increase the sensitivity of these plants to stresses, such as droughts, cold temperatures, insect pests, and disease, leading to increased mortality of canopy trees. Terrestrial acidification affects several important ecological services, including declines in habitat for threatened and endangered species (cultural), declines in forest aesthetics (cultural), declines in forest productivity (provisioning), and increases in forest soil erosion and reductions in water retention (cultural and regulating).

Deposition of nitrogen is also associated with aquatic and terrestrial nutrient enrichment. In estuarine waters, excess nutrient enrichment can lead to eutrophication. Eutrophication of estuaries can disrupt an important source of food production, particularly fish and shellfish production, and a variety of cultural ecosystem services, including water-based recreational and aesthetic services. Terrestrial nutrient enrichment is associated with changes in the types and number of species and biodiversity in terrestrial systems. Excessive nitrogen deposition upsets the balance between native and nonnative plants, changing the ability of an area to support biodiversity. When the composition of species changes, then fire frequency and intensity can also change, as nonnative grasses fuel more frequent and more intense wildfires.

4.3.10.5 Visibility Impairment Benefits

Reducing secondary formation of $PM_{2.5}$ would improve levels of visibility in the U.S. because suspended particles and gases degrade visibility by scattering and absorbing light (U.S. EPA 2009). Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil. Visibility has direct significance to people's enjoyment of daily activities and their overall sense of wellbeing. Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities. Particulate sulfate is the dominant source of regional haze in the eastern U.S. and particulate nitrate is an important contributor to light extinction in California and the upper Midwestern U.S., particularly during winter (U.S. EPA, 2009b). Previous analyses such as U.S. EPA (2012) show that visibility benefits can be a significant welfare benefit category. Without air quality modeling, we are unable to estimate visibility-related benefits, and we are also unable to determine whether the emission reductions associated with this rule would be likely to have a significant impact on visibility in urban areas or Class I areas.

Reductions in emissions of NO_2 will improve the level of visibility throughout the U.S. because these gases (and the particles of nitrate and sulfate formed from these gases) impair visibility by scattering and absorbing light (U.S. EPA, 2009b). Visibility is also referred to as visual air quality (VAQ), and it directly affects people's enjoyment of a variety of daily activities (U.S. EPA, 2009b). Good visibility increases quality of life where individuals live and work, and where they travel for recreational activities, including sites of unique public value, such as the Great Smoky Mountains National Park (U.S. EPA, 2009b).

4.4 Climate Benefits

EPA estimates the climate benefits of CO_2 emissions reductions expected from the final rule using estimates of the social cost of carbon (SC-CO_2) that reflect recent advances in the scientific literature on climate change and its economic impacts and incorporate recommendations made by the National Academies of Science, Engineering, and Medicine (National Academies, 2017). EPA published and used these estimates in the RIA for the December 2023 final oil and natural gas sector rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review" (US EPA 2023c). EPA solicited public comment on the methodology and use of these estimates in the RIA for the Agency's December 2022 oil and natural gas sector supplemental proposal and has conducted an external peer review of these estimates, as described further below. [61]

The SC-CO_2 is the monetary value of the net harm to society associated with a marginal increase in CO_2 emissions in a given year, or the net benefit of avoiding that increase. In principle, SC-CO_2 includes the value of all climate change impacts (both negative and positive), including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-CO_2, therefore, reflects the societal value of reducing emissions of CO_2 by one metric ton and is the theoretically appropriate value to use in conducting benefit-cost analyses of policies that affect CO_2 emissions. In practice, data and modeling limitations restrain the ability of SC-CO_2 estimates to include all physical, ecological, and economic impacts of climate change, implicitly assigning a value of zero to the omitted climate damages. The estimates are, therefore, a partial accounting of climate change impacts and likely underestimate the marginal benefits of abatement.

Since 2008, EPA has used estimates of the social cost of various GHGs (i.e., SC-CO_2, SC-CH_4, and SC-N_2O), collectively referred to as the "social cost of greenhouse gases" (SC-GHG), in analyses of actions that affect GHG emissions. The values used by EPA from 2009 to

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[61] See *https://www.epa.gov/environmental-economics/scghg* for a copy of the final report and other related materials.

2016, and since 2021 — including in the proposal for this rulemaking — have been consistent with those developed and recommended by the Interagency Working Group (IWG) on the SC-GHG; and the values used from 2017 to 2020 were consistent with those required by E.O. 13783, which disbanded the IWG. During 2015–2017, the National Academies conducted a comprehensive review of the SC-CO_2 and issued a final report in 2017 recommending specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process. The IWG was reconstituted in 2021 and E.O. 13990 directed it to develop a comprehensive update of its SC-GHG estimates, recommendations regarding areas of decision-making to which SC-GHG should be applied, and a standardized review and updating process to ensure that the recommended estimates continue to be based on the best available economics and science going forward.

EPA is a member of the IWG and is participating in the IWG's work under E.O. 13990. As noted in previous EPA RIAs, while that process continues, EPA is continuously reviewing developments in the scientific literature on the SC-GHG, including more robust methodologies for estimating damages from emissions, and looking for opportunities to further improve SC-GHG estimation.[62] In the December 2022 oil and natural gas sector supplemental proposal RIA, the Agency included a sensitivity analysis of the climate benefits of the supplemental proposal using a new set of SC-GHG estimates that incorporates recent research addressing recommendations of the National Academies (National Academies, 2017) in addition to using the interim SC-GHG estimates presented in *the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* (IWG, 2021) that the IWG recommended for use until updated estimates that address the National Academies' recommendations are available.

EPA solicited public comment on the sensitivity analysis and the accompanying draft technical report, *External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances*, which explains the methodology underlying

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[62] EPA strives to base its analyses on the best available science and economics, consistent with its responsibilities, for example, under the Information Quality Act.

the new set of estimates, in the December 2022 oil and natural gas supplemental proposal RIA. The response to comments document can be found in the docket for that action.[63]

To ensure that the methodological updates adopted in the technical report are consistent with economic theory and reflect the latest science, EPA also initiated an external peer review panel to conduct a high-quality review of the technical report, completed in May 2023. The peer reviewers commended the agency on its development of the draft update, calling it a much-needed improvement in estimating the SC-GHG and a significant step toward addressing the National Academies' recommendations with defensible modeling choices based on current science. The peer reviewers provided numerous recommendations for refining the presentation and for future modeling improvements, especially with respect to climate change impacts and associated damages that are not currently included in the analysis. Additional discussion of omitted impacts and other updates have been incorporated in the technical report to address peer reviewer recommendations. Complete information about the external peer review, including the peer reviewer selection process, the final report with individual recommendations from peer reviewers, and EPA's response to each recommendation is available on EPA's website.[64]

The remainder of this section provides an overview of the methodological updates incorporated into the SC-GHG estimates used in this final RIA. A more detailed explanation of each input and the modeling process is provided in the final technical report, *Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances*.[65] Appendix B presents the projected benefits of the final rule using the interim SC-GHG (IWG, 2021) estimates used in the proposal RIA for comparison purposes.

The steps necessary to estimate the SC-GHG with a climate change integrated assessment model (IAM) can generally be grouped into four modules: socioeconomics and emissions, climate, damages, and discounting. The emissions trajectories from the socioeconomic module are used to project future temperatures in the climate module. The damage module then translates the temperature and other climate endpoints (along with the projections of socioeconomic variables) into physical impacts and associated monetized economic damages, where the damages are calculated as the amount of money the individuals experiencing the

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[63] *https://www.regulations.gov/docket/EPA-HQ-OAR-2021-0317*.

[64] *https://www.epa.gov/environmental-economics/scghg-tsd-peer-review*.

[65] See *https://www.epa.gov/environmental-economics/scghg* for a copy of the final report and other related materials.

climate change impacts would be willing to pay to avoid them. To calculate the marginal effect of emissions, i.e., the SC-GHG in year "*t*," the entire model is run twice – first as a baseline and second with an additional pulse of emissions in year "*t*." After recalculating the temperature effects and damages expected in all years beyond "*t*" resulting from the adjusted path of emissions, the losses are discounted to a present value in the discounting module. Many sources of uncertainty in the estimation process are incorporated using Monte Carlo techniques by taking draws from probability distributions that reflect the uncertainty in parameters.

The SC-GHG estimates used by EPA and many other federal agencies since 2009 have relied on an ensemble of three widely used IAMs: Dynamic Integrated Climate and Economy (DICE) (Nordhaus, 2010); Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) (Anthoff and Tol, 2013a, 2013b); and Policy Analysis of the Greenhouse Gas Effect (PAGE) (Hope, 2013). In 2010, the IWG harmonized key inputs across the IAMs, but all other model features were left unchanged, relying on the model developers' best estimates and judgments. That is, the representation of climate dynamics and damage functions included in the default version of each IAM as used in the published literature was retained.

The SC-GHG estimates in this RIA no longer rely on the three IAMs (i.e., DICE, FUND, and PAGE) used in previous SC-GHG estimates. As explained previously, EPA uses a modular approach to estimate the SC-GHG, consistent with the National Academies' near-term recommendations. That is, the methodology underlying each component, or module, of the SC-GHG estimation process is developed by drawing on the latest research and expertise from the scientific disciplines relevant to that component. Under this approach, each step in the SC-GHG estimation improves consistency with the current state of scientific knowledge, enhances transparency, and allows for more explicit representation of uncertainty.

The socioeconomic and emissions module relies on a new set of probabilistic projections for population, income, and GHG emissions developed under the Resources for the Future (RFF) Social Cost of Carbon Initiative (Rennert, Prest, et al., 2022). These socioeconomic projections (hereinafter collectively referred to as the RFF-SPs) are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO_2, CH_4, and N_2O) to 2300. Based on a review of available sources of long-run projections necessary for damage calculations, the RFF-SPs stand out as being most consistent with the National Academies' recommendations. Consistent with the National Academies' recommendation, the RFF-SPs were developed using a mix of statistical and expert elicitation techniques to capture uncertainty in a single probabilistic approach, taking into account the likelihood of future emissions mitigation policies and technological developments, and provide the level of disaggregation necessary for damage calculations. Unlike other sources of projections, they provide inputs for estimation out to 2300 without further extrapolation assumptions. Conditional on the modeling conducted for the SC-GHG estimates, this time horizon is far enough in the future to capture the majority of discounted climate damages. Including damages beyond 2300 would increase the estimates of the SC-GHG. As discussed in U.S. EPA (2023c), the use of the RFF-SPs allows for capturing economic growth uncertainty within the discounting module.

The climate module relies on the Finite Amplitude Impulse Response (FaIR) model (IPCC, 2021b; Millar et al., 2017; C. J. Smith et al., 2018), a widely used Earth system model which captures the relationships between GHG emissions, atmospheric GHG concentrations, and global mean surface temperature. The FaIR model was originally developed by Richard Millar, Zeb Nicholls, and Myles Allen at Oxford University, as a modification of the approach used in IPCC AR5 to assess the GWP and GTP (Global Temperature Potential) of different gases. It is open source, widely used (e.g., IPCC (2018, 2021a)) and was highlighted by the National Academies (2017) as a model that satisfies their recommendations for a near-term update of the climate module in SC-GHG estimation. Specifically, it translates GHG emissions into mean surface temperature response and represents the current understanding of the climate and GHG cycle systems and associated uncertainties within a probabilistic framework. The SC-GHG estimates used in this RIA rely on FaIR version 1.6.2 as used by the IPCC (2021a). It provides, with high confidence, an accurate representation of the latest scientific consensus on the relationship between global emissions and global mean surface temperature and offers a code base that is fully transparent and available online. The uncertainty capabilities in FaIR 1.6.2 have been calibrated to the most recent assessment of the IPCC (which importantly narrowed the range of likely climate sensitivities relative to prior assessments). See U.S. EPA (2023c) for more details.

The socioeconomic projections and outputs of the climate module are inputs into the damage module to estimate monetized future damages from climate change.[66] The National Academies' recommendations for the damage module, scientific literature on climate damages, updates to models that have been developed since 2010, as well as the public comments received on individual EPA rulemakings and the IWG's February 2021 TSD, have all helped to identify available sources of improved damage functions. The IWG (e.g., IWG 2010, 2016a, 2021), the National Academies (2017), comprehensive studies (e.g., Rose et al. (2014)), and public comments have all recognized that the damages functions underlying the IWG SC-GHG estimates used since 2013 (taken from DICE 2010 (Nordhaus, 2010); FUND 3.8 (Anthoff and Tol, 2013a, 2013b); and PAGE 2009 (Hope, 2013)) do not include all the important physical, ecological, and economic impacts of climate change. The climate change literature and the science underlying the economic damage functions have evolved, and DICE 2010, FUND 3.8, and PAGE 2009 now lag behind the most recent research. The IWG (e.g., IWG (2010, 2016a, 2021)), the National Academies (2017), comprehensive studies (e.g., Rose et al. (2014)), and public comments have all recognized that the damages functions underlying the IWG SC-GHG estimates used since 2013 (taken from DICE 2010 (Nordhaus, 2010); FUND 3.8 (Anthoff and Tol, 2013a, 2013b); and PAGE 2009 (Hope, 2013)) do not include all of the important physical, ecological, and economic impacts of climate change. The climate change literature and the science underlying the economic damage functions have evolved, and DICE 2010, FUND 3.8, and PAGE 2009 now lag behind the most recent research.

The challenges involved with updating damage functions have been widely recognized. Functional forms and calibrations are constrained by the available literature and need to extrapolate beyond warming levels or locations studied in that literature. Research and public resources focused on understanding how these physical changes translate into economic impacts have been significantly less than the resources focused on modeling and improving our understanding of climate system dynamics and the physical impacts from climate change

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[66] In addition to temperature change, two of the three damage modules used in the SC-GHG estimation require global mean sea level (GMSL) projections as an input to estimate coastal damages. Those two damage modules use different models for generating estimates of GMSL. Both are based off reduced complexity models that can use the FaIR temperature outputs as inputs to the model and generate projections of GMSL accounting for the contributions of thermal expansion and glacial and ice sheet melting based on recent scientific research. Absent clear evidence on a preferred model, the SC-GHG estimates presented in this RIA retain both methods used by the damage module developers. See U.S. EPA (2023c) for more details.

(Auffhammer, 2018). Even so, there has been a large increase in research on climate impacts and damages in the time since DICE 2010, FUND 3.8, and PAGE 2009 were published. Along with this growth, there continues to be wide variation in methodologies and scope of studies, such that care is required when synthesizing the current understanding of impacts or damages. Based on a review of available studies and approaches to damage function estimation, EPA uses three separate damage functions to form the damage module: (1) a subnational-scale, sectoral damage function (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (Carleton et al., 2022; Climate Impact Lab (CIL), 2023; Rode et al., 2021); (2) a country-scale, sectoral damage function (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert, Errickson, et al., 2022); and (3) a meta-analysis-based damage function (based on Howard and Sterner (2017)).

The damage functions in DSCIM and GIVE represent substantial improvements relative to the damage functions underlying the SC-GHG estimates used by EPA to date and reflect the forefront of scientific understanding about how temperature change and SLR lead to monetized net (market and nonmarket) damages for several categories of climate impacts. The models' spatially explicit and impact-specific modeling of relevant processes allow for improved understanding and transparency about mechanisms through which climate impacts are occurring and how each damage component contributes to the overall results, consistent with the National Academies' recommendations. DSCIM addresses common criticisms related to the damage functions underlying current SC-GHG estimates (e.g., Pindyck (2017)) by developing multi-sector, empirically grounded damage functions. The damage functions in the GIVE model offer a direct implementation of the National Academies' near-term recommendation to develop updated sectoral damage functions that are based on recently published work and reflective of the current state of knowledge about damages in each sector. Specifically, the National Academies noted that "[t]he literature on agriculture, mortality, coastal damages, and energy demand provide immediate opportunities to update the [models]" (p. 199 in National Academies (2017)), which are the four damage categories currently in GIVE. A limitation of both models is that the sectoral coverage is still limited, and even the categories that are represented are incomplete. Neither DSCIM nor GIVE yet accommodate estimation of several categories of temperature driven climate impacts (e.g., morbidity, conflict, migration, biodiversity loss) and only represent a limited subset of damages from changes in precipitation. For example, while precipitation is considered in the agriculture sectors in both DSCIM and GIVE, neither model takes into account impacts of flooding, changes in rainfall from tropical storms, and other precipitation related impacts. As another example, the coastal damage estimates in both models do not fully reflect the consequences of SLR-driven salt-water intrusion and erosion, or SLR damages to coastal tourism and recreation. Other missing elements are damages that result from other physical impacts (e.g., ocean acidification, non-temperature-related mortality such as diarrheal disease and malaria) and the many feedbacks and interactions across sectors and regions that can lead to additional damages.[67] See U.S. EPA (2023c) for more discussion of omitted damage categories and other modeling limitations. DSCIM and GIVE do account for the most commonly cited benefits associated with CO_2 emissions and climate change – CO_2 crop fertilization and declines in cold related mortality. As such, while the GIVE- and DSCIM-based results provide state-of-the-science assessments of key climate change impacts, they remain partial estimates of future climate damages resulting from incremental changes in CO_2, CH_4, and N_2O.[68]

Finally, given the still relatively narrow sectoral scope of the recently developed DSCIM and GIVE models, the damage module includes a third damage function that reflects a synthesis of the state of knowledge in other published climate damages literature. Studies that employ meta-analytic techniques[69] offer a tractable and straightforward way to combine the results of multiple studies into a single damage function that represents the body of evidence on climate damages that pre-date CIL and RFF's research initiatives. The first use of meta-analysis to combine multiple climate damage studies was done by Tol (2009) and included 14 studies. The studies in Tol (2009) served as the basis for the global damage function in DICE starting in version 2013R (Nordhaus, 2014). The damage function in the most recent published version of

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[67] The one exception is that the agricultural damage function in DSCIM and GIVE reflects the ways that trade can help mitigate damages arising from crop yield impacts.

[68] One advantage of the modular approach used by these models is that future research on new or alternative damage functions can be incorporated in a relatively straightforward way. DSCIM and GIVE developers have work underway on other impact categories that may be ready for consideration in future updates (e.g., morbidity and biodiversity loss).

[69] Meta-analysis is a statistical method of pooling data and/or results from a set of comparable studies of a problem. Pooling in this way provides a larger sample size for evaluation and allows for a stronger conclusion than can be provided by any single study. Meta-analysis yields a quantitative summary of the combined results and current state of the literature.

DICE, DICE 2016, is from an updated meta-analysis based on a rereview of existing damage studies and included 26 studies published over 1994-2013 (Nordhaus and Moffat, 2017). Howard and Sterner (2017) provide a more recent published peer-reviewed meta-analysis of existing damage studies (published through 2016) and account for additional features of the underlying studies. This study addresses differences in measurement across studies by adjusting estimates such that the data are relative to the same base period. They also eliminate double counting by removing duplicative estimates. Howard and Sterner's final sample is drawn from 20 studies that were published through 2015. Howard and Sterner (2017) present results under several specifications and show that the estimates are somewhat sensitive to defensible alternative modeling choices. As discussed in detail in U.S. EPA (2023c), the damage module underlying the SC-GHG estimates in this RIA includes the damage function specification (that excludes duplicate studies) from Howard and Sterner (2017) that leads to the lowest SC-GHG estimates, all else equal.

The discounting module discounts the stream of future net climate damages to its present value in the year when the additional unit of emissions was released. Given the long-time horizon over which the damages are expected to occur, the discount rate has a large influence on the present value of future damages. Consistent with the findings of National Academies (2017), the economic literature, OMB Circular A-4's guidance for regulatory analysis, and IWG recommendations to date (IWG, 2010, 2013, 2016a, 2016b, 2021), EPA continues to conclude that the consumption rate of interest is the theoretically appropriate discount rate to discount the future benefits of reducing GHG emissions and that discount rate uncertainty should be accounted for in selecting future discount rates in this intergenerational context. OMB's Circular A-4 points out that "the analytically preferred method of handling temporal differences between benefits and costs is to adjust all the benefits and costs to reflect their value in equivalent units of consumption and to discount them at the rate consumers and savers would normally use in discounting future consumption benefits" (OMB, 2003).[70] The damage module described above calculates future net damages in terms of reduced consumption (or monetary consumption equivalents), and so an application of this guidance is to use the consumption discount rate to

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[70] Similarly, OMB's Circular A-4 (2023) points out that "The analytically preferred method of handling temporal differences between benefits and costs is to adjust all the benefits and costs to reflect their value in equivalent units of consumption before discounting them."

calculate the SC-GHG. Thus, EPA concludes that the use of the social rate of return on capital (7 percent under the 2003 OMB Circular A-4 guidance), which does not reflect the consumption rate, to discount damages estimated in terms of reduced consumption would inappropriately underestimate the impacts of climate change for the purposes of estimating the SC-GHG.[71]

For the SC-GHG estimates used in this RIA, EPA relies on a dynamic discounting approach that more fully captures the role of uncertainty in the discount rate in a manner consistent with the other modules. Based on a review of the literature and data on consumption discount rates, the public comments received on individual EPA rulemakings, and the February 2021 TSD, and the National Academies (2017) recommendations for updating the discounting module, the SC-GHG estimates rely on discount rates that reflect more recent data on the consumption interest rate and uncertainty in future rates. Specifically, rather than using a constant discount rate, the evolution of the discount rate over time is defined following the latest empirical evidence on interest rate uncertainty and using a framework originally developed by Ramsey (1928) that connects economic growth and interest rates. The Ramsey approach explicitly reflects (1) preferences for utility in one period relative to utility in a later period and (2) the value of additional consumption as income changes. The dynamic discount rates used to develop the SC-GHG estimates applied in this RIA have been calibrated following the Newell et al. (2022) approach, as applied in Rennert, Errickson, et al. (2022); Rennert, Prest, et al. (2022). This approach uses the Ramsey (1928) discounting formula in which the parameters are calibrated such that (1) the decline in the certainty-equivalent discount rate matches the latest empirical evidence on interest rate uncertainty estimated by Bauer and Rudebusch (2020, 2023) and (2) the average of the certainty-equivalent discount rate over the first decade matches a near-term consumption rate of interest. Uncertainty in the starting rate is addressed by using three near-term target rates (1.5, 2.0, and 2.5 percent) based on multiple lines of evidence on observed market interest rates.

The resulting dynamic discount rate provides a notable improvement over the constant discount rate framework used for SC-GHG estimation in previous EPA RIAs. Specifically, it provides internal consistency within the modeling and a more complete accounting of

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[71] See also the discussion of the inappropriateness of discounting consumption-equivalent measures of benefits and costs using a rate of return on capital in Circular A-4 (OMB, 2003).

uncertainty consistent with economic theory (Arrow et al., 2013; Cropper et al., 2014) and the National Academies' (2017) recommendation to employ a more structural, Ramsey-like approach to discounting that explicitly recognizes the relationship between economic growth and discounting uncertainty. This approach is also consistent with the National Academies (2017) recommendation to use three sets of Ramsey parameters that reflect a range of near-term certainty-equivalent discount rates and are consistent with theory and empirical evidence on consumption rate uncertainty. Finally, the value of aversion to risk associated with net damages from GHG emissions is explicitly incorporated into the modeling framework following the economic literature. See U.S. EPA (2023c) for a more detailed discussion of the entire discounting module and methodology used to value risk aversion in the SC-GHG estimates.

Taken together, the methodologies adopted in this SC-GHG estimation process allow for a more holistic treatment of uncertainty than past estimates used by EPA. The updates incorporate a quantitative consideration of uncertainty into all modules and use a Monte Carlo approach that captures the compounding uncertainties across modules. The estimation process generates nine separate distributions of discounted marginal damages per metric ton – the product of using three damage modules and three near-term target discount rates – for each gas in each emissions year. These distributions have long right tails reflecting the extensive evidence in the scientific and economic literature that shows the potential for lower-probability but higher-impact outcomes from climate change, which would be particularly harmful to society. The uncertainty grows over the modeled time horizon. Therefore, under cases with a lower near-term target discount rate – that give relatively more weight to impacts in the future – the distribution of results is wider. To produce a range of estimates that reflects the uncertainty in the estimation exercise while also providing a manageable number of estimates for policy analysis, EPA combines the multiple lines of evidence on damage modules by averaging the results across the three damage module specifications. The full results generated from the updated methodology for methane and other GHGs (SC-CO_2, SC-CH_4, and SC-N_2O) for emissions years 2020 through 2080 are provided in U.S. EPA (2023c).

Table 4-9 summarizes the resulting averaged certainty-equivalent SC-CO_2 estimates under each near-term discount rate that are used to estimate the climate benefits of the CO_2 emission reductions expected from the final rule. These estimates are reported in 2019 dollars but are otherwise identical to those presented in U.S. EPA (2023c). The SC-CO_2 increase over time within the models — i.e., the societal harm from one metric ton emitted in 2030 is higher than the harm caused by one metric ton emitted in 2027 — because future emissions produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modeled as proportional to GDP.

Table 4-9 Estimates of the Social Cost of CO_2 Values, 2028-2037 (2019 dollars per Metric Tonne CO_2) [a]

	Near-term Ramsey Discount Rate		
Emission Year	**2.5%**	**2%**	**1.5%**
2028	140	220	370
2029	140	220	380
2030	140	230	380
2031	150	230	380
2032	150	230	390
2033	150	240	390
2034	150	240	400
2035	160	240	400
2036	160	250	410
2037	160	250	410

[a] Source: U.S. EPA (2023c). Note: These SC-CO_2 values are identical to those reported in the technical report U.S. EPA (2023c) adjusted for inflation to 2019 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9 (U.S. BEA, 2021). The values are stated in $/metric ton CO_2 and vary depending on the year of CO_2 emissions. This table displays the values rounded to two significant figures. The annual unrounded values used in the calculations in this RIA are available in Appendix A.4 of U.S. EPA (2023c) and at: *www.epa.gov/environmental-economics/scghg*.

The methodological updates described above represent a major step forward in bringing SC-GHG estimation closer to the frontier of climate science and economics and address many of the National Academies' (2017) near-term recommendations. Nevertheless, the resulting SC-CO_2 estimates presented in Table 4-9, still have several limitations, as would be expected for any modeling exercise that covers such a broad scope of scientific and economic issues across a complex global landscape. There are still many categories of climate impacts and associated damages that are only partially or not reflected yet in these estimates and sources of uncertainty that have not been fully characterized due to data and modeling limitations. For example, the modeling omits most of the consequences of changes in precipitation, damages from extreme weather events, the potential for nongradual damages from passing critical thresholds (e.g., tipping elements) in natural or socioeconomic systems, and non-climate mediated effects of

GHG emissions. Importantly, the updated SC-GHG methodology does not yet reflect interactions and feedback effects within, and across, Earth and human systems. For example, it does not explicitly reflect potential interactions among damage categories, such as those stemming from the interdependencies of energy, water, and land use. These, and other, interactions and feedbacks were highlighted by the National Academies as an important area of future research for longer-term enhancements in the SC-GHG estimation framework.

Table 4-10 presents the estimated annual, undiscounted climate benefits of the estimated changes in CO_2 emissions the final rule, using the SC-CO_2 estimates presented in Table 4-9, for the stream of years beginning in 2028 through 2037. Also shown are the present value (PV) of monetized climate benefits discounted back to 2023 and equivalent annualized values (EAV) associated with each of the three SC-CO_2 values. To calculate the present and annualized values of climate benefits in Table 4-10, EPA uses the same discount rate as the near-term target Ramsey rate used to discount the climate benefits from future CO_2 reductions.[72] That is, future climate benefits estimated with the SC-CO_2 at the near-term 2.5 percent, 2 percent, and 1.5 percent Ramsey rate are discounted to the base year of the analysis using a constant 2.5, 2, and 1.5 percent rate, respectively. Note the less stringent regulatory alternative only has unquantified benefits associated with the finalized requirements for PM CEMS. As a result, there are no quantified benefits associated with this regulatory option.

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[72] As discussed in U.S. EPA (2023c), the error associated with using a constant discount rate rather than the certainty-equivalent rate path to calculate the present value of a future stream of monetized climate benefits is small for analyses with moderate time frames (e.g., 30 years or less). EPA (2023c) also provides an illustration of the amount that climate benefits from reductions in future emissions will be underestimated by using a constant discount rate relative to the more complicated certainty-equivalent rate path.

Table 4-10 Stream of Projected Climate Benefits under the Final Rule from 2028 through 2037 (discounted to 2023, millions of 2019 dollars)[a]

	Near-term Ramsey Discount Rate		
Emission Year	**2.5%**	**2%**	**1.5%**
2028[b]	7.9	13	22
2029	7.9	13	22
2030[b]	-4.3	-7.1	-12
2031	-4.3	-7.1	-12
2032	12	19	34
2033	12	19	33
2034	12	19	33
2035[b]	11	19	33
2036	11	19	33
2037	11	19	33
PV and EAV			
PV	**76**	**130**	**220**
EAV	**8.7**	**14**	**24**

[a] Climate benefits are based on changes (reductions) in CO_2 emissions and are calculated using updated estimates of the SC-CO_2 from U.S. EPA (2023c).
[b] IPM run years.

Unlike many environmental problems where the causes and impacts are distributed more locally, GHG emissions are a global externality making climate change a true global challenge. GHG emissions contribute to damages around the world regardless of where they are emitted. Because of the distinctive global nature of climate change, in the RIA for this final rule EPA centers attention on a global measure of climate benefits from GHG reductions.

Consistent with all IWG recommended SC-GHG estimates to date, the SC-GHG values presented in Table 4-9 provide a global measure of monetized damages from CO_2, and Table 4-10and Table 4-11present the monetized global climate benefits of the CO_2 emission reductions expected from the final rule. This approach is the same as that taken in EPA regulatory analyses from 2009 through 2016 and since 2021. It is also consistent with guidance in OMB Circular A-4 (OMB 2003, 2023) that recommends reporting of important international effects.[73] EPA also

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[73] The 2003 version of OMB Circular A-4 states when a regulation is likely to have international effects, "these effects should be reported"; while OMB recommends that international effects be reported separately, the guidance also explains that "[d]ifferent regulations may call for different emphases in the analysis, depending on the nature and complexity of the regulatory issues." (OMB 2003). The 2023 update to Circular A-4 states that "In certain contexts, it may be particularly appropriate to include effects experienced by noncitizens residing abroad in your primary analysis. Such contexts include, for example, when:

notes that EPA's cost estimates in RIAs, including the cost estimates contained in this RIA, regularly do not differentiate between the share of compliance costs expected to accrue to U.S. firms versus foreign interests, such as to foreign investors in regulated entities.[74] A global perspective on climate effects is therefore consistent with the approach EPA takes on costs. There are many reasons, as summarized in this section —and as articulated by OMB and in IWG assessments (IWG, 2010, 2013, 2016a, 2016b, 2021), the 2015 Response to Comments (IWG, 2015), in detail in U.S. EPA (2023c), in Appendix A of the Response to Comments document for the December 2023 final oil and natural gas sector rulemaking — why EPA focuses on the global value of climate change impacts when analyzing policies that affect GHG emissions.

International cooperation and reciprocity are essential to successfully addressing climate change, as the global nature of GHGs means that a ton of GHGs emitted in any other country harms those in the U.S. just as much as a ton emitted within the territorial U.S. Assessing the benefits of U.S. GHG mitigation activities requires consideration of how those actions may affect mitigation activities by other countries, as those international mitigation actions will provide a benefit to U.S. citizens and residents by mitigating climate impacts that affect U.S. citizens and residents. This is a classic public goods problem because each country's reductions benefit everyone else, and no country can be excluded from enjoying the benefits of other countries' reductions. The only way to achieve an efficient allocation of resources for emissions reduction on a global basis — and so benefit the U.S. and its citizens and residents — is for all

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- assessing effects on noncitizens residing abroad provides a useful proxy for effects on U.S. citizens and residents that are difficult to otherwise estimate;
- assessing effects on noncitizens residing abroad provides a useful proxy for effects on U.S. national interests that are not otherwise fully captured by effects experienced by particular U.S. citizens and residents (e.g., national security interests, diplomatic interests, etc.);
- regulating an externality on the basis of its global effects supports a cooperative international approach to the regulation of the externality by potentially inducing other countries to follow suit or maintain existing efforts; or
- international or domestic legal obligations require or support a global calculation of regulatory effects" (OMB 2023. Due to the global nature of the climate change problem, the OMB recommendations of appropriate contexts for considering international effects are relevant to the CO_2 emission reductions expected from the final rule. For example, as discussed in this RIA, a global focus in evaluating the climate impacts of changes in CO_2 emissions supports a cooperative international approach to GHG mitigation by potentially inducing other countries to follow suit or maintain existing efforts, and the global SC-CO_2 estimates better capture effects on U.S. citizens and residents and U.S. national interests that are difficult to estimate and not otherwise fully captured.

[74] For example, in the RIA for the 2018 Proposed Reconsideration of the Oil and Natural Gas Sector Emission Standards for New, Reconstructed, and Modified Sources, EPA acknowledged that some portion of regulatory costs will likely "accru[e] to entities outside U.S. borders" through foreign ownership, employment, or consumption (EPA 2018, p. 3-13). In general, a significant share of U.S. corporate debt and equities are foreign-owned, including in the oil and gas industry.

countries to base their policies on global estimates of damages. A wide range of scientific and economic experts have emphasized the issue of international cooperation and reciprocity as support for assessing global damages of GHG emission in domestic policy analysis. Using a global estimate of damages in U.S. analyses of regulatory actions allows the U.S. to continue to actively encourage other nations, including emerging major economies, to also assess global climate damages of their policies and to take steps to reduce emissions. For example, many countries and international institutions have already explicitly adapted the global SC-GHG estimates used by EPA in their domestic analyses (e.g., Canada, Israel) or developed their own estimates of global damages (e.g., Germany), and recently, there has been renewed interest by other countries to update their estimates since the draft release of the updated SC-GHG estimates presented in the December 2022 oil and natural gas sector supplemental proposal RIA.[75] Several recent studies have empirically examined the evidence on international GHG mitigation reciprocity, through both policy diffusion and technology diffusion effects. See U.S. EPA (2023c) for more discussion.

For all of these reasons, EPA believes that a global metric is appropriate for assessing the climate benefits of avoided GHG emissions in this final RIA. In addition, as emphasized in the National Academies (2017) recommendations, "[i]t is important to consider what constitutes a domestic impact in the case of a global pollutant that could have international implications that impact the United States." The global nature of GHG pollution and its impacts means that U.S. interests are affected by climate change impacts through a multitude of pathways and these need to be considered when evaluating the benefits of GHG mitigation to U.S. citizens and residents. The increasing interconnectedness of global economy and populations means that impacts occuring outside of U.S. borders can have significant impacts on U.S. interests. Examples of affected interests include direct effects on U.S. citizens and assets located abroad, international trade, and tourism, and spillover pathways such as economic and political destabilization and global migration that can lead to adverse impacts on U.S. national security, public health, and

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[75] In April 2023, the government of Canada announced the publication of an interim update to their SC-GHG guidance, recommending SC-GHG estimates identical to EPA's updated estimates presented in the December 2022 Supplemental Proposal RIA. The Canadian interim guidance will be used across all Canadian federal departments and agencies, with the values expected to be finalized by the end of the year. *https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/social-cost-ghg.html*.

humanitarian concerns. Those impacts point to the global nature of the climate change problem and are better captured within global measures of the social cost of GHGs.

In the case of these global pollutants, for the reasons articulated in this section, the assessment of global net damages of GHG emissions allows EPA to fully disclose and contextualize the net climate benefits of CO_2 emission reductions expected from this final rule. EPA disagrees with public comments received on the December 2022 oil and natural gas sector supplemental proposal that suggested that EPA can or should use a metric focused on benefits resulting solely from changes in climate impacts occuring within U.S. borders. The global models used in the SC-GHG modeling described above do not lend themselves to be disaggregated in a way that could provide sufficiently robust information about the distribution of the rule's climate benefits to citizens and residents of particular countries, or population groups across the globe and within the U.S. Two of the models used to inform the damage module, the GIVE and DSCIM models, have spatial resolution that allows for some geographic disaggregation of future climate impacts across the world. This permits the calculation of a partial GIVE and DSCIM-based SC-GHG measuring the damages from four or five climate impact categories projected to physically occur within the U.S., respectively, subject to caveats. As discussed at length in U.S. EPA (2023c), these damage modules are only a partial accounting and do not capture all of the pathways through which climate change affects public health and welfare. For example, this modeling omits most of the consequences of changes in precipitation, damages from extreme weather events (e.g., wildfires), the potential for nongradual damages from passing critical thresholds (e.g., tipping elements) in natural or socioeconomic systems, and non-climate mediated effects of GHG emissions other than CO_2 fertilization (e.g., tropospheric ozone formation due to CH_4 emissions). Thus, they only cover a subset of potential climate change impacts. Furthermore, as discussed at length in U.S. EPA (EPA, 2023f), the damage modules do not capture spillover or indirect effects whereby climate impacts in one country or region can affect the welfare of residents in other countries or regions—such as how economic and health conditions across countries will impact U.S. business, investments, and travel abroad.

Additional modeling efforts can and have shed further light on some omitted damage categories. For example, the Framework for Evaluating Damages and Impacts (FrEDI) is an open-source modeling framework developed by EPA to facilitate the characterization of net annual climate change impacts in numerous impact categories within the contiguous U.S. and monetize the associated distribution of modeled damages (Sarofim et al., 2021; U.S. EPA, 2021b)).[76] The additional impact categories included in FrEDI reflect the availability of U.S.-specific data and research on climate change effects. As discussed in U.S. EPA (2023c), results from FrEDI show that annual damages resulting from climate change impacts within the contiguous U.S. (CONUS) (i.e., excluding Hawaii, Alaska, and U.S. territories) and for impact categories not represented in GIVE and DSCIM are expected to be substantial. For example, FrEDI estimates a partial SC-CO_2 of \$36/mtCO_2 for damages physically occurring within CONUS for 2030 emissions (under a 2 percent near-term Ramsey discount rate), compared to a GIVE and DSCIM-based U.S.-specific SC-CO_2 of \$16/mtCO_2 and \$14/mtCO_2, respectively, for 2030 emissions (2019 dollars).

While the FrEDI results help to illustrate how monetized damages physically occurring within CONUS increase as more impacts are reflected in the modeling framework, they are still subject to many of the same limitations associated with the DSCIM and GIVE damage modules, including the omission or partial modeling of important damage categories.[77,78] Finally, none of these modeling efforts–GIVE, DSCIM, and FrEDI–reflect non-climate mediated effects of GHG emissions experienced by U.S. populations (other than CO_2 fertilization effects on agriculture).

Taken together, applying the U.S.-specific partial SC-GHG estimates derived from the multiple lines of evidence described above to the GHG emissions reduction expected under the final rule would yield substantial benefits. For example, the present value of the climate benefits of the final rule over the 2028 to 2037 period as measured by FrEDI from climate change

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[76] The FrEDI framework and Technical Documentation have been subject to a public review comment period and an independent external peer review, following guidance in the EPA Peer-Review Handbook for Influential Scientific Information (ISI). Information on the FrEDI peer-review is available at the EPA Science Inventory (EPA Science Inventory, 2021).

[77] Another method that has produced estimates of the effect of climate change on U.S.-specific outcomes uses a top-down approach to estimate aggregate damage functions. Published research using this approach include total-economy empirical studies that econometrically estimate the relationship between GDP and a climate variable, usually temperature. As discussed in U.S. EPA (2023c), the modeling framework used in the existing published studies using this approach differ in important ways from the inputs underlying the SC-GHG estimates described above (e.g., discounting, risk aversion, and scenario uncertainty). Hence, we do not consider this line of evidence in the analysis for this RIA. Updating the framework of total-economy empirical damage functions to be consistent with the methods described in this RIA and U.S. EPA (2023c) would require new analysis. Finally, because total-economy empirical studies estimate market impacts, they do not include any non-market impacts of climate change (e.g., heat related mortality) and therefore are also only a partial estimate. EPA will continue to review developments in the literature and explore ways to better inform the public of the full range of GHG impacts.

[78] FrEDI estimates a partial SC-CO_2 of \$33/mtCO_2 for damages physically occurring within CONUS for 2030 emissions (under a 2 percent near-term Ramsey discount rate) (Hartin et al., 2023), compared to a GIVE and DSCIM-based U.S.-specific SC-CO_2 of \$14/mtCO_2 and \$12/mtCO_2, respectively, for 2030 emissions (2019 USD).

impacts in CONUS are estimated to be $19 million under a 2 percent near-term Ramsey discount rate.[79] However, the numerous explicitly omitted damage categories and other modeling limitations discussed above and throughout U.S. EPA (2023c) make it likely that these estimates underestimate the benefits to U.S. citizens and residents of the GHG reductions from the final rule; the limitations in developing a U.S.-specific estimate that accurately captures direct and spillover effects on U.S. citizens and residents further demonstrates that it is more appropriate to use a global measure of climate benefits from GHG reductions. EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various damages to U.S. populations from climate impacts and reciprocal international mitigation activities, and explore ways to better inform the public of the full range of GHG impacts.

4.5 Total Benefits

Table 4-11 presents the total health and climate benefits[80] for the final rule. Note that while we do not project emissions reductions under the less stringent option, we do expect there to be benefits from the CEMS requirement. However, since we are unable to quantify these benefits, for simplicity, we omit results for the less stringent option in this section.

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[79] DCIM and GIVE use global damage functions. Damage functions based on only U.S.-data and research, but not for other parts of the world, were not included in those models. FrEDI does make use of some of this U.S.-specific data and research and as a result has a broader coverage of climate impact categories.

[80] Monetized climate benefits are discounted using a 2 percent discount rate, consistent with EPA's updated estimates of the SC-CO_2. OMB has long recognized that climate effects should be discounted only at appropriate consumption-based discount rates. Because the SC-CO_2 estimates reflect net climate change damages in terms of reduced consumption (or monetary consumption equivalents), the use of the social rate of return on capital (7 percent under OMB Circular A-4 (2003)) to discount damages estimated in terms of reduced consumption would inappropriately underestimate the impacts of climate change for the purposes of estimating the SC-CO_2. See Section 4 for more discussion.

Table 4-11 Stream of Monetized Benefits under the Final Rule from 2028 through 2037 (discounted to 2023, millions of 2019 dollars)[a]

	Values Calculated using 2% Discount Rate			Values Calculated using 3% Discount Rate			Values Calculated using 7% Discount Rate		
Year	**Health Benefits[b]**	**Climate Benefits[c,d]**	**Total**	**Health Benefits**	**Climate Benefits (discounted at 2%)[c,d]**	**Total**	**Health Benefits**	**Climate Benefits (discounted at 2%)[c,d]**	**Total**
2028	79	13	92	71	13	84	52	13	66
2029	79	13	92	71	13	84	50	13	63
2030	27	-7.1	20	24	-7.1	17	16	-7.1	9.1
2031	27	-7.1	20	24	-7.1	16	16	-7.1	8.4
2032	14	19	33	13	19	32	8.0	19	27
2033	14	19	34	13	19	32	7.7	19	27
2034	14	19	34	12	19	32	7.3	19	27
2035	14	19	33	12	19	31	7.0	19	26
2036	14	19	33	12	19	31	6.7	19	26
2037	14	19	33	12	19	31	6.4	19	25
PV	**300**	**130**	**420**	**260**	**130**	**390**	**180**	**130**	**300**
EAV	**33**	**14**	**47**	**31**	**14**	**45**	**25**	**14**	**39**

Non-Monetized Benefits[e]

Benefits from reductions of about 900 to 1000 pounds of Hg annually

Benefits from reductions about 4 to 7 tons of non-Hg HAP metals annually

Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

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[a] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

[b] Monetized air quality-related benefits include those related to public health associated with reductions in PM$_{2.5}$ and ozone concentrations. The estimated value of the air quality-related health benefits included here are the larger of the two estimates presented in Table 4-5, Table 4-6, and Table 4-7.

[c] Monetized climate benefits are based on reductions in CO$_2$ emissions and are calculated using three different estimates of the social cost of carbon dioxide (SC-CO$_2$) (under 1.5 percent, 2 percent, and 2.5 percent near-term Ramsey discount rates). For the presentational purposes of this table, we show the climate benefits associated with the SC-CO$_2$ at the 2 percent near-term Ramsey discount rate. Please see Table 4-10 for the full range of monetized climate benefit estimates.

[d] The small increases and decreases in climate and health benefits and related EJ impacts result from very small changes in fossil dispatch and coal use relative to the baseline. For context, the projected increase in CO$_2$ emission of less than 40,000 tons in 2030 is roughly one percent of the emissions of a mid-size coal plant operating at availability (about 4 million tons).

[e] The list of non-monetized benefits does not include all potential non-monetized benefits. See Table 4-8 for a more complete list.

4.6 References

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ECONOMIC IMPACTS

5.1 Overview

Economic impact analyses focus on changes in market prices and output levels. If changes in market prices and output levels in the primary markets are significant enough, impacts on other markets may also be examined. Both the magnitude of costs needed to comply with a rule and the distribution of these costs among affected facilities can have a role in determining how the market will change in response to a rule. This section analyzes the potential impacts on small entities and the potential labor impacts associated with this rulemaking. For additional discussion of impacts on fuel use and electricity prices, see Section 3.

5.2 Small Entity Analysis

For the final rule, EPA performed a small entity screening analysis for impacts on all affected EGUs and non-EGU facilities by comparing compliance costs to historic revenues at the ultimate parent company level. This is known as the cost-to-revenue or cost-to-sales test, or the "sales test." The sales test is an impact methodology EPA employs in analyzing entity impacts as opposed to a "profits test," in which annualized compliance costs are calculated as a share of profits. The sales test is frequently used because revenues or sales data are commonly available for entities impacted by EPA regulations, and profits data normally made available are often not the true profit earned by firms because of accounting and tax considerations. Also, the use of a sales test for estimating small business impacts for a rulemaking is consistent with guidance offered by EPA on compliance with the Regulatory Flexibility Act (RFA)[81] and is consistent with guidance published by the U.S. Small Business Administration's (SBA) Office of Advocacy that suggests that cost as a percentage of total revenues is a metric for evaluating cost increases on small entities in relation to increases on large entities.[82]

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[81] See U.S. EPA. (2006). *Final Guidance for EPA Rulewriters: Regulatory Flexibility Act as Amended by the Small Business and Regulatory Enforcement Fairness Act.* Available at: *https://www.epa.gov/sites/production/files/2015-06/documents/guidance-regflexact.pdf.*

[82] See U.S. SBA Office of Advocacy. (2017). *A Guide for Government Agencies: How to Comply with the Regulatory Flexibility Act.* Available at*: https://advocacy.sba.gov/2017/08/31/a-guide-for-government-agencies-how-to-comply-with-the-regulatory-flexibility-act.*

5.2.1 Methodology

This section presents the methodology and results for estimating the impact of the rule on small EGU entities in the year of compliance, 2028, based on the following endpoints:

- annual economic impacts of the final rule on small entities, and
- ratio of small entity impacts to revenues from electricity generation.

For this analysis, EPA first considered EGUs that are subject to MATS requirements and for which EPA assumed additional controls would be necessary to meet the requirements of the finalized rule. We then refined this list of MATS-affected EGUs, complementing the list with units for which the projected impacts exceeds either of the two criteria below relative to the baseline:

- Fuel use (BTUs) changes by +/- 1 percent or more
- Generation (GWh) changes by +/- 1 percent or more

Please see Section 3 for more discussion of the power sector modeling.

Based on these criteria, EPA identified a total of 377 potentially affected EGUs warranting examination in 2028 in this RFA analysis. Next, we determined power plant ownership information, including the name of associated owning entities, ownership shares, and each entity's type of ownership. We primarily used data from Hitachi — Power Grids, The Velocity Suite I 2020 ("VS"), supplemented by limited research using publicly available data. Majority owners of power plants with affected EGUs were categorized as one of the seven ownership types. These ownership types are:

1. **Investor-Owned Utility (IOU):** Investor-owned assets (e.g., a marketer, independent power producer, financial entity) and electric companies owned by stockholders, etc.
2. **Cooperative (Co-Op):** Non-profit, customer-owned electric companies that generate and/or distribute electric power.
3. **Municipal:** A municipal utility, responsible for power supply and distribution in a small region, such as a city.
4. **Sub-division**: Political subdivision utility is a county, municipality, school district, hospital district, or any other political subdivision that is not classified as a municipality under state law.
5. **Private**: Similar to an investor-owned utility, however, ownership shares are not openly traded on the stock markets.

6. **State:** Utility owned by the state.
7. **Federal:** Utility owned by the federal government.

Next, EPA used both the D&B Hoovers online database and the VS database to identify the ultimate owners of power plant owners identified in the VS database. This was necessary, as many majority owners of power plants (listed in VS) are themselves owned by other ultimate parent entities (listed in D&B Hoovers). In these cases, the ultimate parent entity was identified via D&B Hoovers, whether domestically or internationally owned.

EPA followed SBA size standards to determine which non-government ultimate parent entities should be considered small entities in this analysis. These SBA size standards are specific to each industry, each having a threshold level of either employees, revenue, or assets below which an entity is considered small. SBA guidelines list all industries, along with their associated North American Industry Classification System (NAICS) code and SBA size standard. Therefore, it was necessary to identify the specific NAICS code associated with each ultimate parent entity in order to understand the appropriate size standard to apply. Data from D&B Hoovers were used to identify the NAICS codes for most of the ultimate parent entities. In many cases, an entity that is a majority owner of a power plant is itself owned by an ultimate parent entity with a primary business other than electric power generation. Therefore, it was necessary to consider SBA entity size guidelines for the range of NAICS codes listed in Table 5-1. This table represents the range of NAICS codes and areas of primary business of ultimate parent entities that are majority owners of potentially affected EGUs in EPA's IPM base case.

Table 5-1 SBA Size Standards by NAICS Code

NAICS Code	NAICS U.S. Industry Title	Size Standard (millions of dollars)	Size Standard (number of employees)
211120	Crude Petroleum Extraction		1,250
212221	Gold Ore Mining		1,500
221111	Hydroelectric Power Generation		500
221112	Fossil Fuel Electric Power Generation		750
221113	Nuclear Electric Power Generation		750
221114	Solar Electric Power Generation		250
221115	Wind Electric Power Generation		250
221116	Geothermal Electric Power Generation		250
221117	Biomass Electric Power Generation		250
221118	Other Electric Power Generation		250
221121	Electric Bulk Power Transmission and Control		500
221122	Electric Power Distribution		1,000
221210	Natural Gas Distribution		1,000
221310	Water Supply and Irrigation Systems	$41.00	
221320	Sewage Treatment Facilities	$35.00	
221330	Steam and Air Conditioning Supply	$30.00	
311221	Wet Corn Milling		1,250
311224	Soybean and Other Oilseed Processing		1,000
322121	Paper (except Newsprint) Mills		1,250
325611	Soap and Other Detergent Manufacturing		1,000
325920	Explosives Manufacturing		750
331110	Iron and Steel Mills and Ferroalloy Manufacturing		1,500
332313	Plate Work Manufacturing		750
332911	Industrial Valve Manufacturing		750
333611	Turbine and Turbine Generator Set Unit Manufacturing		1,500
333613	Mechanical Power Transmission Equipment Manufacturing		750
423520	Coal and Other Mineral and Ore Merchant Wholesalers		200
423990	Other Miscellaneous Durable Goods Merchant Wholesalers		100
424690	Other Chemical and Allied Products Merchant Wholesalers		175
424720	Petroleum and Petroleum Products Merchant Wholesalers		200
522110	Commercial Banking	$750.00	
523210	Securities and Commodity Exchanges	$47.00	
523910	Miscellaneous Intermediation	$44.25	
523930	Investment Advice	$41.50	
524126	Direct Property and Casualty Insurance Carriers		1,500
525910	Open-End Investment Funds	$37.50	
525990	Other Financial Vehicles	$40.00	
541330	Engineering Services	$22.50	
541611	Administrative Management and General Management Consulting Services	$21.50	
541715	Research and Development in the Physical, Engineering, and Life Sciences (except Nanotechnology and Biotechnology)		1,000
551112	Offices of Other Holding Companies	$45.50	

NAICS Code	NAICS U.S. Industry Title	Size Standard (millions of dollars)	Size Standard (number of employees)
611310	Colleges, Universities and Professional Schools	$30.50	
721110	Hotels (except Casino Hotels) and Motels	$35.00	
813910	Business Associations	$13.50	

Note: Based on size standards effective at the time EPA conducted this analysis (SBA size standards, effective December 19, 2022. Available at the following link: *https://www.sba.gov/document/support—table-size-standards*). Source: SBA, 2022.

EPA compared the relevant entity size criterion for each ultimate parent entity to the SBA size standard noted in Table 5-1. We used the following data sources and methodology to estimate the relevant size criterion values for each ultimate parent entity:

- **Employment, Revenue, and Assets**: EPA used the D&B Hoovers database as the primary source for information on ultimate parent entity employee numbers, revenue, and assets.[83] In parallel, EPA also considered estimated revenues from affected EGUs based on analysis of IPM parsed-file[84] estimates for the baseline for 2028. EPA assumed that the ultimate parent entity revenue was the larger of the two revenue estimates. In limited instances, supplemental research was also conducted to estimate an ultimate parent entity's number of employees, revenue, or assets.

- **Population**: Municipal entities are defined as small if they serve populations of less than 50,000.[85] EPA primarily relied on data from the Ventyx database and the U.S. Census Bureau to inform this determination.

Ultimate parent entities for which the relevant measure is less than the SBA size standard were identified as small entities and carried forward in this analysis.

In the projected results for 2028, EPA identified 377 potentially affected EGUs, owned by 104 entities. Of these, EPA identified 45 potentially affected EGUs owned by 24 small entities included in the power sector baseline.

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[83] Estimates of sales were used in lieu of revenue estimates when revenue data were unavailable.

[84] IPM output files report aggregated results for "model" plants (i.e., aggregates of generating units with similar operating characteristics). Parsed files approximate the IPM results at the generating unit level.

[85] The Regulatory Flexibility Act defines a small government jurisdiction as the government of a city, county, town, township, village, school district, or special district with a population of less than 50,000 (5 U.S.C. section 601(5)). For the purposes of the RFA, States and tribal governments are not considered small governments. EPA's *Final Guidance for EPA Rulewriters: Regulatory Flexibility Act* is located here: *https://www.epa.gov/sites/default/files/2015-06/documents/guidance-regflexact.pdf*.

The chosen compliance strategy will be primarily a function of the unit's marginal control costs and its position relative to the marginal control costs of other units. To attempt to account for each potential control strategy, EPA estimates compliance costs as follows:

$$C_{Compliance} = \Delta\, C_{Operating+Retrofit} + \Delta\, C_{Fuel} + \Delta\, R$$

where C represents a component of cost as labeled and Δ R represents the change in revenues, calculated as the difference in value of electricity generation between the baseline case and the rule in in 2028.

Realistically, compliance choices and market conditions can combine such that an entity may actually experience a reduction in any of the individual components of cost. Under the rule, some units will forgo some level of electricity generation (and thus revenues) to comply, and this impact will be lessened on these entities by the projected increase in electricity prices under the rule. On the other hand, those units increasing generation levels will see an increase in electricity revenues and as a result, lower net compliance costs. If entities are able to increase revenue more than an increase in fuel cost and other operating costs, ultimately, they will have negative net compliance costs (or increased profit). Overall, small entities are not projected to install relatively costly emissions control retrofits but may choose to do so in some instances. Because this analysis evaluates the total costs along each of the compliance strategies laid out above for each entity, it inevitably captures gains such as those described. As a result, what we describe as cost is actually a measure of the net economic impact of the rule on small entities.

For this analysis, EPA used IPM-parsed output to estimate costs based on the parameters above, at the unit level. These impacts were then summed for each small entity, adjusting for ownership share. Net impact estimates were based on the following: operating and retrofit costs, sale or purchase of allowances, and the change in fuel costs or electricity generation revenues under the finalized MATS requirements relative to the base case. These individual components of compliance costs were estimated as follows:

1. **Operating and retrofit costs** ($\Delta\, C_{Operating+Retrofit}$): EPA projected which compliance option would be selected by each EGU in 2028 and applied the appropriate cost to this choice (for details, please see Section 3 of this RIA). For 2028, IPM projected retrofit costs were also included in the calculation.

2. **Fuel costs** (ΔC_{Fuel})**:** The change in fuel expenditures under the final requirements was estimated by taking the difference in projected fuel expenditures between the IPM estimates under the final requirements and the baseline.

3. **Value of electricity generated** (ΔC_{Fuel})**:** To estimate the value of electricity generated, the projected level of electricity generation is multiplied by the regional-adjusted retail electricity price ($/MWh) estimate, for all entities except those categorized as private in Ventyx. See Section 3 for a discussion of the Retail Price Model, which was used to estimate the change in the retail price of electricity. For private entities, EPA used the wholesale electricity price instead of the retail electricity price because most of the private entities are independent power producers (IPP). IPPs sell their electricity to wholesale purchasers and do not own transmission facilities. Thus, their revenue was estimated with wholesale electricity prices.

5.2.2 Results

As indicated above, the use of a sales test for estimating small business impacts for a rulemaking is consistent with guidance offered by EPA on compliance with the RFA and is consistent with guidance published by the SBA's Office of Advocacy that suggests that cost as a percentage of total revenues is a metric for evaluating cost increases on small entities in relation to increases on large entities. EPA assessed the economic and financial impacts of the rule using the ratio of compliance costs to the value of revenues from electricity generation, focusing in particular on entities for which this measure is greater than 1 percent.

The projected impacts, including compliance costs, of the rule on small entities are summarized in Table 5-2. All costs are presented in 2019 dollars. We projected the annual net compliance cost to small entities to be approximately $2.0 million in 2028. Relative to the baseline, the rule is projected to generate compliance cost reductions greater than 1 percent of baseline revenue for one of the 24 small entities directly impacted, and compliance cost increases greater than 1 percent are projected for two. The remaining 23 entities are not projected to experience compliance cost changes of more than 1 percent. Of the 24 entities considered in this analysis, two are holding units projected to experience compliance cost increases greater than 1 percent of generation revenue at a facility level as well as at a parent holding company level.

Table 5-2 Projected Impacts of Final Rule on Small Entities in 2028

EGU Ownership Type	Number of Potentially Affected Entities	Total Net Compliance Cost (millions 2019 dollars)	Number of Small Entities with Compliance Costs >1% of Generation Revenues
Subdivision	1	-0.029	0
Investor Owned	3	-0.056	0
Private	7	-0.059	0
Co-op	13	2.1	1
Total	**24**	**2.0**	1

5.2.3 Conclusion

Making a determination that there is not a significant economic impact on a substantial number of small entities (often referred to as a “SISNOSE”) requires an assessment of whether an estimated economic impact is significant and whether that impact affects a substantial number of small entities. EPA identified 104 potentially affected EGU entities in the projection year of 2028. Of these, EPA identified 24 small entities affected by the rule, and of these, three small entities may experience costs of greater than 1 percent of revenues. Based on this analysis, for this rule overall we conclude that the estimated costs for the final rule will not have a significant economic impact on a substantial number of small entities.

5.3 Labor Impacts

This section discusses potential employment impacts of this regulation. As economic activity shifts in response to a regulation, typically there will be a mix of declines and gains in employment in different parts of the economy over time and across regions. To present a complete picture, an employment impact analysis will describe the potential positive and negative changes in employment levels. There are significant challenges when trying to evaluate the employment effects of an environmental regulation due to a wide variety of other economic changes that can affect employment, including the impact of the coronavirus pandemic on labor markets and the state of the macroeconomy generally. Considering these challenges, we look to the economics literature to provide a constructive framework and empirical evidence. To simplify, we focus on impacts on labor demand related to compliance behavior. Environmental regulation may also affect labor supply through changes in worker health and productivity (Zivin and Neidell, 2018).

Economic theory of labor demand indicates that employers affected by environmental regulation may increase their demand for some types of labor, decrease demand for other types, or for still other types, not change their demand at all (Berman and Bui, 2001; Deschenes, 2018; Morgenstern et al., 2002). To study labor demand impacts empirically, a growing literature has compared employment levels at facilities subject to an environmental regulation to employment levels at similar facilities not subject to that environmental regulation; some studies find no employment effects, and others find significant differences. For example, see Berman and Bui (2001), Greenstone (2002), Ferris et al. (2014), and Curtis (2018, 2020). A variety of conditions can affect employment impacts of environmental regulation, including baseline labor market conditions and employer and worker characteristics such as occupation and industry. Changes in employment may also occur in different sectors related to the regulated industry, both upstream and downstream, or in sectors producing substitute or complimentary products. Employment impacts in related sectors are often difficult to measure. Consequently, we focus our labor impacts analysis primarily on the directly regulated facilities and other EGUs and related fuel markets.

This section discusses and projects potential employment impacts for the utility power, coal and natural gas production sectors that may result from the final rule. EPA has a long history of analyzing the potential impacts of air pollution regulations on changes in the amount of labor needed in the power generation sector and directly related sectors. The analysis conducted for this RIA builds upon the approaches used in the past and takes advantage of newly available data to improve the assumptions and methodology.[86]

The results presented in this section are based on a methodology that estimates the impact on employment based on the differences in projections between two modeling scenarios: the baseline scenario, and a scenario that represents the implementation of the rule. The estimated employment difference between these scenarios can be interpreted as the incremental effect of the rule on employment in this sector. As discussed in Section 3, there is uncertainty related to the future baseline projections. Because the incremental employment estimates presented in this section are based on projections discussed in Section 3, it is important to highlight the relevance

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[86] For a detailed overview of this methodology, including all underlying assumptions, see the U.S. EPA Methodology for Power Sector-Specific Employment Analysis, available in the docket.

of the Section 3 uncertainty discussion to the analysis presented in this section. Note that there is also uncertainty related to the employment factors applied in this analysis, particularly factors informing job-years related to relatively new technologies, such as energy storage, on which there is limited data to base assumptions.

Like previous analyses, this analysis represents an evaluation of "first-order employment impacts" using a partial equilibrium modeling approach. It includes some of the potential ripple effects of these impacts on the broader economy. These ripple effects include the secondary job impacts in both upstream and downstream sectors. The analysis includes impacts on upstream sectors including coal, natural gas, and uranium. However, the approach does not analyze impacts on other fuel sectors, nor does it analyze potential impacts related to transmission or distribution. This approach excludes the economy-wide employment effects of changes to energy markets (such as higher or lower forecasted electricity prices). This approach also excludes labor impacts that are sometimes reflected in a benefits analysis for an environmental policy, such as increased productivity from a healthier workforce and reduced absenteeism due to fewer sick days of employees and dependent family members (e.g., children).

5.3.1 Overview of Methodology

The methodology includes the following two general approaches, based on the available data. The first approach uses detailed employment data that are available for several types of generation technologies in the 2020 U.S. Energy and Employment Report (USEER).[87] For employment related to other electric power sector generating and pollution control technologies, the second approach uses information available in the U.S. Economic Census.

Detailed employment inventory data are available regarding recent employment related to coal, hydro, natural gas, geothermal, wind, and solar generation technologies as well as battery storage. The data enables the creation of technology-specific factors that can be applied to model projections of capacity (reported in MW) and generation (reported in megawatt-hours, or MWh) to estimate impacts on employment. Since employment data are only available in aggregate by fuel type, it is necessary to disaggregate by labor type to differentiate between types of jobs or tasks for categories of workers. For example, some types of employment remain constant

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[87] *https://www.usenergyjobs.org/.*

throughout the year and are largely a function of the size of a generator, e.g., fixed operation and maintenance activities, while others are variable and are related to the amount of electricity produced by the generator, e.g., variable operation and maintenance activities.

The approach can be summarized in three basic steps:

- Quantify the total number of employees by fuel type in a given year;
- Estimate total fixed operating & maintenance (FOM), variable operating & maintenance (VOM), and capital expenditures by fuel type in that year; and
- Disaggregate total employees into three expenditure-based groups and develop factors for each group (FTE/MWh, FTE/MW-year, FTE/MW new capacity).

Where detailed employment data are unavailable, it is possible to estimate labor impacts using labor intensity ratios. These factors provide a relationship between employment and economic output and are used to estimate employment impacts related to construction and operation of pollution control retrofits, as well as some types of electric generation technologies.

For a detailed overview of this methodology, including all underlying assumptions and the types of employment represented by this analysis, see the U.S. EPA Methodology for Power Sector-Specific Employment Analysis, available in the docket.

5.3.2 Overview of Power Sector Employment

In this section we focus on employment related to electric power generation, as well as coal and natural gas extraction because these are the segments of the power sector that are most relevant to the projected impacts of the rule. Other segments not discussed here include other fuels, energy efficiency, and transmission, distribution, and storage. The statistics presented here are based on the 2020 USEER, which reports data from 2019.[88]

In 2019, the electric power generation sector employed nearly 900,000 people. Relative to 2018, this sector grew by over 2 percent, despite job losses related to nuclear and coal generation. These losses were offset by increases in employment related to other generating technologies, including natural gas, solar, and wind. The largest component of total 2019

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[88] While 2020 data are available in the 2021 version of this report, this section of the RIA utilizes 2019 data because this year does not reflect any short-term trends related to the COVID-19 pandemic. The annual report is available at: *https://www.usenergyjobs.org/.*

employment in this sector is construction (33 percent). Other components of the electric power generation workforce include utility workers (20 percent), professional and business service employees (20 percent), manufacturing (13 percent), wholesale trade (8 percent), and other (5 percent). In 2019, jobs related to solar and wind generation represent 31 percent and 14 percent of total jobs, respectively, and jobs related to coal generation represent 10 percent of total employment.

In addition to generation-related employment, we also look at employment related to coal and natural gas use in the electric power sector. In 2019, the coal industry employed about 75,000 workers. Mining and extraction jobs represent the vast majority of total coal-related employment in 2019 (74 percent). The natural gas fuel sector employed about 276,000 employees in 2019. About 60 percent of those jobs were related to mining and extraction.

5.3.3 Projected Sectoral Employment Changes due to the Final Rule

Electric generating units subject to the Hg and fPM emission limits in this rule will likely use various Hg and PM control strategies to comply. EPA estimates that 11.6 GW of operational coal capacity would either need to improve existing PM controls or install new PM controls to comply with the final rule in 2028. The various PM control upgrades that EPA assumes would be necessary to achieve with the emissions limits analyzed are summarized in Table 3-8.

Based on these power sector modeling projections, we estimate an increase in construction-related job-years related to the installation of new pollution controls under the rule, as well as the construction of new generating capacity. In 2028, we estimate an increase of approximately 1,600 construction-related job-years related to the construction of new pollution controls or control upgrades and an increase of approximately 200 job-years related to the construction of new capacity. In 2030, we estimate a small decrease in construction job-years for new pollution controls and new capacity, followed by an increase of 500 construction job-years for new capacity in 2035. Construction-related job-year changes are one-time impacts, occurring during each year of the multi-year periods during which construction of new capacity is completed. Construction-related figures in Table 5-3 represent a point estimate of incremental changes in construction jobs for each year (for a three-year construction projection, this table presents one-third of the total jobs for that project).

Table 5-3 Projected Changes in Labor Utilization: Construction-Related (Number of Job-Years of Employment in a Single Year)

	2028	2030	2035
New Pollution Controls	1,600	<100	<100
New Capacity	200	<100	500

Notes: "<100" denotes an increase or decrease of fewer than 100 job-years. A large share of the construction-related job years is attributable to construction of energy storage, a relatively new technology on which there is limited data to base labor assumptions.

We also estimate changes in the number of job-years related to recurring non-construction employment. Recurring employment changes are job-years associated with annual recurring jobs including operating and maintenance activities and fuel extraction jobs. Newly built generating capacity creates a recurring stream of positive job-years, while retiring generating capacity, as well as avoided capacity builds, create a stream of negative job-years. Consistent with the small projected changes in generation over 2028 through 2035, this rule is expected to result in small impacts in recurring non-construction jobs. Table 5-4 provides detailed estimates of recurring non-construction employment changes.

Table 5-4 Projected Changes in Labor Utilization: Recurring Non-Construction (Number of Job-Years of Employment in a Single Year)

	2028	2030	2035
Pollution Controls	<100	<100	<100
Existing Capacity	<100	<100	<100
New Capacity	<100	<100	<100
Fuels (Coal, Natural Gas, Uranium)	<100	<100	<100
Coal	*<100*	*<100*	*<100*
Natural Gas	*<100*	*<100*	*<100*
Uranium	*<100*	*<100*	*<100*

Note: "<100" denotes an increase or decrease of fewer than 100 job-years; Numbers may not sum due to rounding.

5.3.4 Conclusions

Generally, there are significant challenges when trying to evaluate the employment effects due to an environmental regulation from employment effects due to a wide variety of other economic changes, including the impact of the coronavirus pandemic on labor markets and the state of the macroeconomy generally. For EGUs, this rule may result in a sizable near-term increase in construction-related jobs related to the installation of new pollution controls, and any changes in recurring non-construction employment are expected to be small.

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ENVIRONMENTAL JUSTICE IMPACTS

6.1 Introduction

E.O. 12898 directs EPA to "achiev[e] environmental justice (EJ) by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects" (59 FR 7629, February 16, 1994), termed disproportionate impacts in this section. Additionally, E.O. 13985 was signed to advance racial equity and support underserved communities through Federal government actions (86 FR 7009, January 20, 2021). Most recently, E.O. 14096 (88 FR 25251, April 26, 2023) strengthens the directives for achieving environmental justice that are set out in E.O. 12898. EPA defines EJ as the just treatment and meaningful involvement of all people regardless of race, color, national origin, Tribal affiliation, disability, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. EPA further defines the term just treatment to mean that "no group of people should bear a disproportionate burden of environmental harms and risks, including those resulting from the negative environmental consequences of industrial, governmental, and commercial operations or programs and policies."[89] Meaningful involvement means that: (1) potentially affected populations have an appropriate opportunity to participate in decisions about a proposed activity that will affect their environment and/or health; (2) the public's contribution can influence the regulatory Agency's decision; (3) the concerns of all participants involved will be considered in the decision-making process; and (4) the rule-writers and decision-makers seek out and facilitate the involvement of those potentially affected.

The term "disproportionate impacts" refers to differences in impacts or risks that are extensive enough that they may merit Agency action.[90] In general, the determination of whether a disproportionate impact exists is ultimately a policy judgment which, while informed by analysis, is the responsibility of the decision-maker. The terms "difference" or "differential" indicate an analytically discernible distinction in impacts or risks across population groups. It is the role of the analyst to assess and present differences in anticipated impacts across population

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[89] See, e.g., "Environmental Justice." *EPA.gov*, U.S. Environmental Protection Agency, 4 Mar. 2021, *https://www.epa.gov/environmentaljustice*.

[90] See *https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis*.

groups of concern for both the baseline and regulatory options, using the best available information (both quantitative and qualitative) to inform the decision-maker and the public.

The Presidential Memorandum on Modernizing Regulatory Review (86 FR 7223; January 20, 2021) calls for procedures to "take into account the distributional consequences of regulations, including as part of a quantitative or qualitative analysis of the costs and benefits of regulations, to ensure that regulatory initiatives appropriately benefit, and do not inappropriately burden disadvantaged, vulnerable, or marginalized communities." Under E.O. 13563, federal agencies may consider equity, human dignity, fairness, and distributional considerations, where appropriate and permitted by law. For purposes of analyzing regulatory impacts, EPA relies upon its June 2016 "Technical Guidance for Assessing Environmental Justice in Regulatory Analysis,"[91] which provides recommendations that encourage analysts to conduct the highest quality analysis feasible, recognizing that data limitations, time, resource constraints, and analytical challenges will vary by media and circumstance. The Technical Guidance states that a regulatory action may involve potential EJ concerns if it could: (1) create new disproportionate impacts; (2) exacerbate existing disproportionate impacts; or (3) present opportunities to address existing disproportionate impacts through the action under development.

A reasonable starting point for assessing the need for a more detailed EJ analysis is to review the available evidence from the published literature and from community input on what factors may make population groups of concern more vulnerable to adverse effects (e.g., underlying risk factors that may contribute to higher exposures and/or impacts). It is also important to evaluate the data and methods available for conducting an EJ analysis. EJ analyses can be grouped into two types, both of which are informative, but not always feasible for a given rulemaking:

1. **Baseline:** Describes the current (pre-control) distribution of exposures and risk, identifying potential disparities.
2. **Policy:** Describes the distribution of exposures and risk after the regulatory option(s) have been applied (post-control), identifying how potential disparities change in response to the rulemaking.

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[91] See *https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis*.

EPA's 2016 Technical Guidance does not prescribe or recommend a specific approach or methodology for conducting EJ analyses, though a key consideration is consistency with the assumptions underlying other parts of the regulatory analysis when evaluating the baseline and regulatory options.

6.2 Analyzing EJ Impacts in this Final Rule

In addition to the benefits assessment (see Section 4), EPA considers potential EJ concerns associated with this final rulemaking. A potential EJ concern is defined as "the actual or potential lack of fair treatment or meaningful involvement of communities with EJ concerns in the development, implementation and enforcement of environmental laws, regulations and policies."[92] For analytical purposes, this concept refers more specifically to "disproportionate impacts on communities with EJ concerns that may exist prior to or that may be created by the final regulatory action." Although EJ concerns for each rulemaking are unique and should be considered on a case-by-case basis, EPA's EJ Technical Guidance states that "[t]he analysis of potential EJ concerns for regulatory actions should address three questions:

1. Are there potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern in the baseline?
2. Are there potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern for the regulatory option(s) under consideration?
3. For the regulatory option(s) under consideration, are potential EJ concerns created [, exacerbated,] or mitigated compared to the baseline?"

To address these questions, EPA developed an analytical approach that considers the purpose and specifics of the rulemaking, as well as the nature of known and potential exposures across various demographic groups. While the final rule targets HAP emissions, other local air pollutants emissions may also be reduced, such as NO_X and SO_2. NO_X and SO_2 emissions can lead to localized exposures that may be associated with health effects in nearby populations at sufficiently high concentrations and certain populations may be at increased risk of exposure-related health effects, such as people with asthma.

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[92] See *https://www.epa.gov/environmentaljustice/technical-guidance-assessing-environmental-justice-regulatory-analysis*.

As HAP exposure results generated as part of the 2020 Residual Risk analysis were below both the presumptive acceptable cancer risk threshold and the noncancer health benchmarks, and this final regulation should further reduce exposure to HAP, there are no 'disproportionate and adverse effects' of potential EJ concern. Therefore, we did not perform a quantitative EJ assessment of HAP risk. In addition, technical limitations prevented analysis of NO_X and SO_2 emission reductions. While HAP, NO_2, and SO_2 exposures and concentrations were not directly evaluated as part of this EJ assessment, due to the potential for reductions in these and other environmental stressors nearby affected sources, EPA qualitatively discussed EJ impacts of HAP (Section 6.3) and conducted a proximity analysis to evaluate the potential EJ implications of changes in localized exposures (Section 6.4).[93]

As this final rule is also expected to reduce ambient $PM_{2.5}$ and ozone concentrations, EPA conducted a quantitative analysis of modeled changes in $PM_{2.5}$ and ozone concentrations across the continental U.S. resulting from the control strategies projected to occur under the rule, characterizing aggregated and distributional exposures both prior to and following implementation of the final regulatory option in 2028, 2030, and 2035 (Section 6.5 and 6.7). It is important to note that due to the small magnitude of underlying emissions changes, and the corresponding small magnitude of the ozone and $PM_{2.5}$ concentration changes, the rule is expected to have only a small impact on the distribution of exposures across each demographic group. As the final rule is also focused on climate impacts resulting from emissions reductions directly targeted in this rulemaking, EPA qualitatively discussed climate impacts in Section 6.6.

Unique limitations and uncertainties are specific to each type of analysis, which are described prior to presentation of analytic results in the subsections below.

6.3 Qualitative Assessment of HAP Impacts

As required by section 112(n)(1)(A) of the CAA, EPA has determined that it is appropriate and necessary to regulate HAP emissions from coal- and oil-fired EGUs. This determination was driven by the significant public health risks and harms posed by prior levels of EGU emissions as evaluated against the availability and costs of emissions controls that could be employed to reduce this harmful pollution. As part of the appropriate and necessary

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[93] The 2016 NO_X ISA and 2017 SO_X ISA identified people with asthma, children, and older adults as being at increased risk of NO_2- and SO_2-related health effects and the 2017 SO_X ISA.

determination, the Administrator specifically considered the impacts of EGU HAP emissions on different populations and concluded that certain parts of the U.S. population may be especially vulnerable to Hg emissions based on their characteristics or circumstances. In some cases, the enhanced vulnerability relates to life stage (e.g., fetuses, infants, young children). In other cases, the enhanced vulnerability can be ascribed to the communities in which the population lives. In this second category, the greater sensitivity to HAP emissions can be attributed to poorer levels of overall health (e.g., higher rates of cardiovascular disease, nutritional deficiencies) or to dietary practices which are more common in some low-income communities of color (e.g., subsistence fishers). The net effect is that certain sub-populations may be especially vulnerable to EGU HAP emissions and that these emissions are a potential EJ concern.

Of the HAP potentially impacted by this final rulemaking, Hg is a persistent and bioaccumulative toxic metal that can be readily transported and deposited to soil and aquatic environments where it is transformed by microbial action into MeHg.[94] Consumption of fish is the primary pathway for human exposure to MeHg. MeHg bioaccumulates in the aquatic food web eventually resulting in highly concentrated levels of MeHg within larger fish.[95] A NAS Study reviewed the effects of MeHg on human health and concluded that it is highly toxic to multiple human and animal organ systems. Of particular concern is chronic prenatal exposure via maternal consumption of foods containing MeHg. Elevated exposure has been associated with developmental neurotoxicity and manifests as poor performance on neurobehavioral tests, particularly on tests of attention, fine motor function, language, verbal memory, and visual-spatial ability. Because the impacts of the neurodevelopmental effects of MeHg are greatest during periods of rapid brain development, developing fetuses, infants, and young children are particularly vulnerable. In particular, children born to populations with high fish consumption (e.g., people consuming fish as a dietary staple) or impaired nutritional status may be especially susceptible to adverse neurodevelopmental outcomes. As part of the 2023 Final A&N Review, EPA evaluated how the neurodevelopmental and cardiovascular risks varied across populations. That analysis completed in support of the appropriate and necessary determination (addressing the EGU sector collectively) suggested that subsistence fisher populations that are racially,

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[94] U.S. EPA. 1997. Mercury Study Report to Congress. EPA–452/R–97–003 December 1997.

[95] National Research Council (NAS). 2000. Toxicological Effects of MeHg. Committee on the Toxicological Effects of MeHg, Board on Environmental Studies and Toxicology, National Research Council.

culturally, geographically, and/or income-differentiated could experience elevated exposures relative to not only the general population but also the population of subsistence fishers generally. As noted in Section 4 of this document, while previous EPA assessments have shown that current modeled exposures are well below the RfD, we conclude that further reductions in Hg emissions from lignite-fired EGUs covered in this final action should further reduce exposures for the subsistence fisher sub-population. However, as we do not expect appreciable adverse health effects as a result of HAP emissions from this source category, we have not conducted quantitative or qualitative analyses to assess specific Hg-related impacts of this action for EJ communities of potential concern or how those impacts differ from U.S. population-wide effects.

6.4 Demographic Proximity Analyses of Existing Facilities

Demographic proximity analyses allow one to assess the potentially vulnerable populations residing near affected facilities as a proxy for exposure and the potential for adverse health impacts that may occur at a local scale due to economic activity at a given location including noise, odors, traffic, and emissions such as NO_2 and SO_2 covered under this EPA action and not modeled elsewhere in this RIA.

Although baseline proximity analyses are presented here, several important caveats should be noted. Emissions are expected to both decrease and increase from the rulemaking in the three modeled future years, so communities near affected facilities could experience either improvements or worsening in air quality from directly emitted pollutants. It should also be noted that facilities may vary widely in terms of the impacts they already pose to nearby populations. In addition, proximity to affected facilities does not capture variation in baseline exposure across communities, nor does it indicate that any exposures or impacts will occur and should not be interpreted as a direct measure of exposure or impact. These points limit the usefulness of proximity analyses when attempting to answer questions from EPA’s EJ Technical Guidance.

Demographic proximity analyses were performed for all plants with at least one coal-fired unit greater than 25 MW without retirement or gas conversion plans before 2029 affected by this final rulemaking. Due to the distinct regulatory requirements, the following subsets of affected facilities were separately evaluated:

- Coal plants with units potentially impacted by the final Hg standard revision (12 facilities): Comparison of the percentage of various populations (race/ethnicity, age, education, poverty status, income, and linguistic isolation) living near the facilities to average national levels.
- Coal plants with units potentially impacted by the final fPM standard revision (21 facilities): Comparison of the percentage of various populations (race/ethnicity, age, education, poverty status, income, and linguistic isolation) living near the facilities to average national levels.

The current analysis identified all census blocks with centroids within a 10-km radius of the latitude/longitude location of each facility, and then linked each block with census-based demographic data.[96] The total population within a specific radius around each facility is the sum of the population for every census block within that specified radius, based on each block's population provided by the 2020 decennial Census.[97] Statistics on race, ethnicity, age, education level, poverty status and linguistic isolation were obtained from the Census' American Community Survey (ACS) 5-year averages for 2016-2020. These data are provided at the block group level. For the purposes of this analysis, the demographic characteristics of a given block group – that is, the percentage of people in different races/ethnicities, the percentage without a high school diploma, the percentage that are below the poverty level, the percentage that are below two times the poverty level, and the percentage that are linguistically isolated – are presumed to also describe each census block located within that block group.

In addition to facility-specific demographics, the demographic composition of the total population within the specified radius (e.g., 10 km) for all facilities was also computed (e.g., all EGUs potentially impacted by the Hg standard revision). In calculating the total populations, to avoid double-counting, each census block population was only counted once. That is, if a census block was located within the selected radius (i.e., 10 km) for multiple facilities, the population of that census block was only counted once in the total population. Finally, this analysis compares the demographics at each specified radius (i.e., 10 km) to the demographic composition of the nationwide population.

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[96] The 10-km distance was determined to be the shortest radius around these units that captured a large enough population to avoid excessive demographic uncertainty.

[97] The location of the Census block centroid is used to determine if the entire population of the Census block is assumed to be within the specified radius. It is unknown how sensitive these results may be to different methods of population estimation, such as aerial apportionment.

Table 6-1For the population living within 10 km of lignite-fired coal plants potentially impacted by the Hg standard, the percentage of the population that is American Indian and Alaska Native Tribes is above the national average (0.9 percent versus 0.6 percent), and the percentage of the population that is Hispanic/Latino or Other/Multiracial is below the corresponding national averages. The percentage of the population that is Black, below the poverty level and below two times the poverty level is similar to the national averages. Finally, the percentage of the population that is in linguistic isolation is below the national average.

The population living within 10 km of the units potentially impacted by the PM standard is 86 percent White. The percentage of the population that is below two times the poverty level is above the national average (32 percent versus 29 percent). The percentage of the population in the other demographic categories is near or below the national averages.

Table 6-1 Proximity Demographic Assessment Results Within 10 km of Coal-Fired Units Greater than 25 MW Without Retirement or Gas Conversion Plans Before 2029 Affected by this Rulemaking [a,b]

Demographic Group	Nationwide Average for Comparison	Population within 10 km Coal plants potentially impacted by Hg standard	Coal plants potentially impacted by fPM standard
Total Population	329,824,950	17,790	233,575
Number of Facilities	-	12	28
Race and Ethnicity by Percent			
White	60%	79%	86%
Black	12%	12%	7%
American Indian and Alaska Native Tribes	0.60%	0.9%	0.3%
Hispanic or Latino[2]	19%	5%	5%
Other and Multiracial	9%	2%	3%
Income by Percent			
Below Poverty Level	13%	12%	14%
Below 2x Poverty Level	29%	28%	32%
Education by Percent			
>25 and w/o a HS Diploma	12%	13%	12%
Linguistically Isolated by Percent			
Linguistically Isolated	5%	2%	1%

[a] The nationwide population count and all demographic percentages are based on the Census' 2016-2020 American Community Survey five-year block group averages and include Puerto Rico. Demographic percentages based on different averages may differ. The total population counts are based on the 2020 Decennial Census block populations.

[b] To avoid double counting, the "Hispanic or Latino" category is treated as a distinct demographic category for these analyses. A person is identified as one of five racial/ethnic categories above: White, Black, American Indian and Alaska Native Tribes, Other and Multiracial, or Hispanic/Latino. A person who identifies as Hispanic or Latino is counted as Hispanic/Latino for this analysis, regardless of what race this person may have also identified as in the Census. Includes white and nonwhite.

6.5 EJ $PM_{2.5}$ and Ozone Exposure Impacts

This EJ air pollutant exposure[98] analysis aims to evaluate the potential for EJ concerns related to $PM_{2.5}$ and ozone exposures[99] among potentially vulnerable populations. To assess EJ ozone and $PM_{2.5}$ exposure impacts, we focus on the first and third of the three EJ questions from

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[98] The term exposure is used here to describe estimated $PM_{2.5}$ and ozone concentrations and not individual dosage.

[99] Air quality surfaces used to estimate exposures are based on 12-km grids. Additional information on air quality modeling can be found in the air quality modeling information section.

EPA's 2016 EJ Technical Guidance,[100] which ask if there are potential EJ concerns associated with stressors affected by the regulatory action for population groups of concern in the baseline and if those potential EJ concerns in the baseline are exacerbated, unchanged, or mitigated under the regulatory options being considered.[101]

To address these questions with respect to the $PM_{2.5}$ and ozone exposures, EPA developed an analytical approach that considers the purpose and specifics of this rulemaking, as well as the nature of known and potential exposures and impacts. Specifically, as 1) this final rule affects EGUs across the U.S., which typically have tall stacks that result in emissions from these sources being dispersed over large distances, and 2) both ozone and $PM_{2.5}$ can undergo long-range transport, it is appropriate to conduct an EJ assessment of the contiguous U.S. Given the availability of modeled $PM_{2.5}$ and ozone air quality surfaces under the baseline and final regulatory option, we conduct an analysis of changes in $PM_{2.5}$ and ozone concentrations resulting from the emission changes projected under the final rule as compared to the baseline scenario, characterizing average and distributional exposures the analysis years 2028, 2030, and 2035. However, several important caveats of this analysis are as follows:

- The baseline scenarios for 2028, 2030, and 2035 represent EGU emissions expected in 2028, 2030, and 2035 respectively, but emissions from all other sources are projected to the year 2026. The 2028, 2030, and 2035 baselines therefore do not capture any anticipated changes in ambient ozone and $PM_{2.5}$ between 2026 and 2028, 2030, or 2035 that would occur due to emissions changes from sources other than EGUs.
- Modeling of post-policy air quality concentration changes are based on state-level emission data paired with facility-level baseline 2026 emissions that were available in the summer 2021 version of IPM. While the baseline spatial patterns represent ozone and $PM_{2.5}$ concentrations associated with the facility level emissions described above, the post-policy air quality surfaces will capture expected ozone and $PM_{2.5}$ changes that result

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[100] U.S. Environmental Protection Agency (EPA), 2015. Guidance on Considering Environmental Justice During the Development of Regulatory Actions. *https://www.epa.gov/sites/default/files/2015-06/documents/considering-ej-in-rulemaking-guide-final.pdf.*

[101] EJ question 2 asks if there are potential EJ concerns (i.e., disproportionate burdens across population groups) associated with environmental stressors affected by the regulatory action for population groups of concern for the regulatory options under consideration We use the results from questions 1 and 3 to gain insight into the answer to EJ question 2 in the summary (Section 6.7), for several reasons. Importantly, the total magnitude of differential exposure burdens with respect to ozone and $PM_{2.5}$ among population groups at the national scale has been fairly consistent pre- and post-policy implementation across recent rulemakings. As such, differences in nationally aggregated exposure burden averages between population groups before and after the rulemaking tend to be very similar. Therefore, as disparities in pre- and post-policy burden results appear virtually indistinguishable, the difference attributable to the rulemaking can be more easily observed when viewing the change in exposure impacts, and as we had limited available time and resources, we chose to provide quantitative results on the pre-policy baseline and policy-specific impacts only, which related to EJ questions 1 and 3.

from state-to-state emissions changes but will not capture heterogenous changes in emissions from multiple facilities within a single state.

- Air quality simulation input information are at a 12-km grid resolution and population information is either at the Census tract- or county-level, potentially masking impacts at geographic scales more highly resolved than the input information.
- The two specific air pollutant metrics evaluated in this assessment, warm season maximum daily eight-hour ozone average concentrations and average annual $PM_{2.5}$ concentrations, are focused on longer-term exposures that have been linked to adverse health effects. This assessment does not evaluate disparities in other potentially health-relevant metrics, such as shorter-term exposures to ozone and $PM_{2.5}$.
- $PM_{2.5}$ EJ impacts were limited to exposures, and do not extend to health effects, given additional uncertainties associated with estimating health effects stratified by demographic population and the ability to predict differential $PM_{2.5}$-attributable EJ health impacts.

Population variables considered in this EJ exposure assessment include race, ethnicity, educational attainment, employment status, health insurance status, life expectancy, linguistic isolation, poverty status, redlined areas, tribal land, age, and sex (Table 6-2).[102,103,104,105] Note that these variables are different than the proximity analysis because criteria pollutants have nationwide impacts rather than the localized impacts that are investigated for HAP in the proximity analysis. There are also fewer demographic uncertainties at a national scale which allows us to use an expanded set of variables for a nationwide analysis.

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[102] Population projections stratified by race/ethnicity, age, and sex are based on economic forecasting models developed by Woods and Poole (2015). The Woods and Poole database contains county-level projections of population by age, sex, and race out to 2050, relative to a baseline using the 2010 Census data. Population projections for each county are determined simultaneously with every other county in the U.S to consider patterns of economic growth and migration. County-level estimates of population percentages within the poverty status and educational attainment groups were derived from 2015-2019 5-year average ACS estimates. Additional information can be found in Appendix J of the BenMAP-CE User's Manual (*https://www.epa.gov/benmap/benmap-ce-manual-and-appendices*).

[103] The Tribal Land variable was also added in response to recent Executive Orders that have emphasized the need for more detailed analysis on the impacts on American Indians. The Tribal Lands variable focuses specifically on populations who live on Tribal lands in addition to quantifying those whose race is American Indian but may or may not live on Tribal lands.

[104] EPA acknowledges the recent comments about cumulative risk assessment and is currently in the process of developing cumulative risk assessment methods for our quantitative environmental justice analyses. In the interim, this rulemaking utilizes the "life expectancy" and "redlining" variables as a proxy to identify communities with higher or lower exposure to cumulative risks. EPA continues to improve its methodology based on its framework for a Cumulative Risk Assessment as well as guidance from multiple Executive Orders and intend to assess cumulative risk more accurately in future rulemakings.

[105] An additional population variable that is not included in this analysis is persons with disability. Persons with disability is a new environmental justice metric listed in E.O. 14096 (88 FR 25251, April 26, 2023), and EPA is currently developing analytical techniques/tools to evaluate its impact on our environmental analyses.

The demographic groups and processing methodology for each dataset are described below. County-level datasets were generated for 3,109 counties in the contiguous U.S.

Table 6-2 Demographic Populations Included in the $PM_{2.5}$ and Ozone EJ Exposure Analyses

Demographic	Groups	Ages	Spatial Scale of Population Data
Race	Asian; American Indian; Black; White	0-99	Census tract
Ethnicity	Hispanic; Non-Hispanic	0-99	Census tract
Educational Attainment	High school degree or more; No high school degree	25-99	Census tract
Employment Status	Employed; Unemployed; Not in the labor force	0-99	County
Health Insurance	Insured; Uninsured	0-64	County
Linguistic Isolation	Speaks English "very well" or better; Speaks English less than "very well" OR Speaks English "well" or better; Speaks English less than "well"	0-99	Census tract
Poverty Status	Above the poverty line; Below the poverty line OR Above 2x the poverty line; Below 2x the poverty line	0-99	Census tract
Redlined Areas	HOLC[a] Grades A-C; HOLC Grade D; Not graded by HOLC	0-99	Census tract
Life Expectancy	Top 75%; Bottom 25%	0-99	Census tract
Tribal Land	Tribal land; Not Tribal land	0-99	Census tract
Age	Children Adults Older Adults	0-17 18-64 65-99	Census tract
Sex	Female; Male	0-99	Census tract

[a] *Home Owners' Loan Corporation (HOLC)*

6.5.1 Populations Predicted to Experience $PM_{2.5}$ and Ozone Air Quality Changes

While EPA projects the final rule will lead to both decreases and increases in emissions in different regions, the magnitude of the air pollution exposure changes from the final rule is quite small across the three future years analyzed. For all three future years evaluated, there were no discernable $PM_{2.5}$ or ozone concentration changes out to the hundredths digit, reiterating the small magnitude of national average $PM_{2.5}$ or ozone changes (Figure 6-1 and Figure 6-2).

6.5.2 $PM_{2.5}$ EJ Exposure Analysis

We evaluated the potential for EJ concerns among potentially vulnerable populations resulting from exposure to $PM_{2.5}$ under the baseline and final regulatory option in this rule. This was done by characterizing the projected distribution of $PM_{2.5}$ exposures both prior to and following implementation of the final rule in 2028, 2030, and 2035.

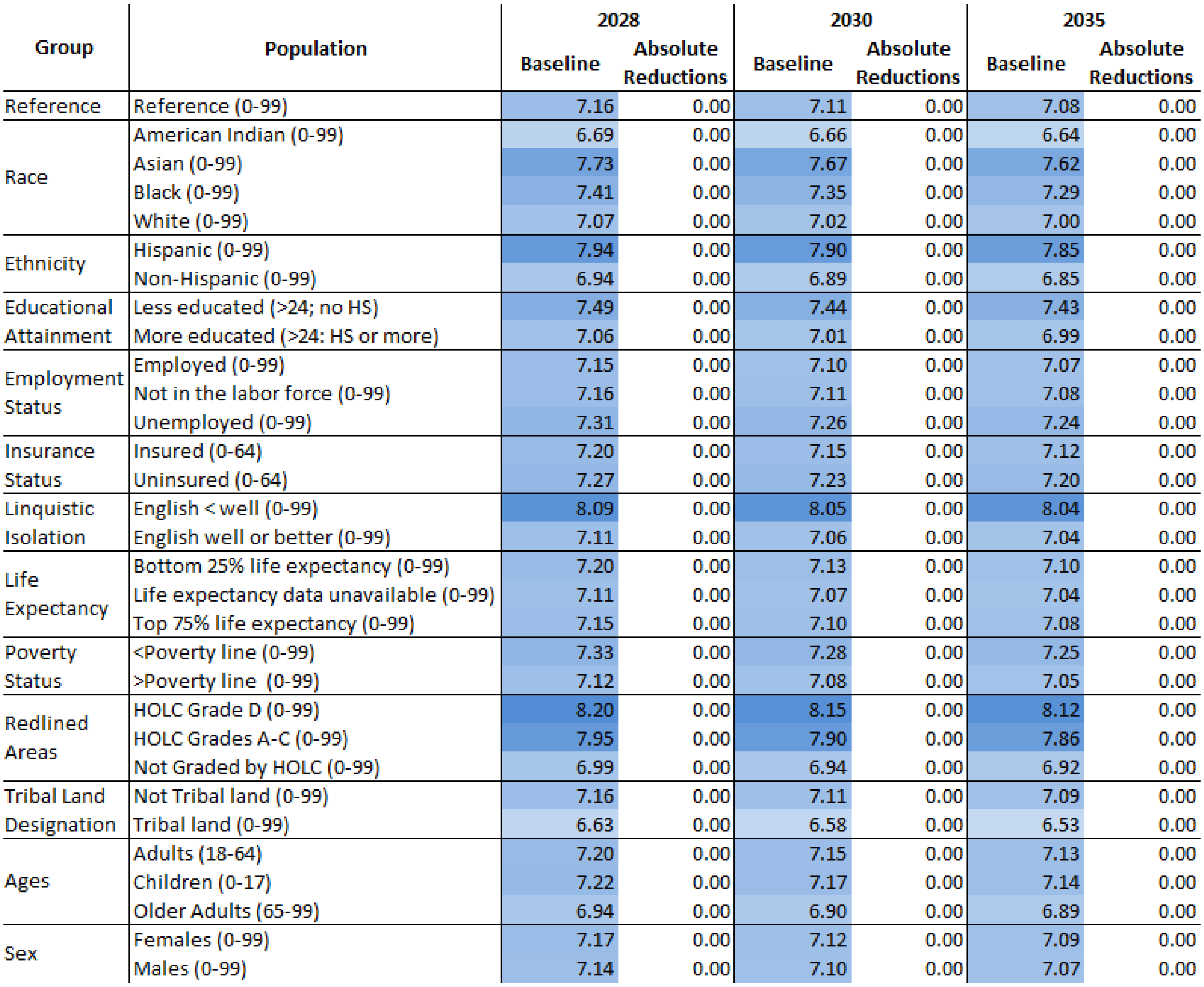
As this analysis is based on the same $PM_{2.5}$ spatial fields as the benefits assessment (see Appendix A for a discussion of the spatial fields), it is subject to similar types of uncertainty (see Section 4.3.8 for a discussion of the uncertainty). A particularly germane limitation for this analysis is that the magnitude of the expected concentration changes is quite small, likely making uncertainties associated with the various input data more relevant.

6.5.2.1 National Aggregated Results

National average baseline $PM_{2.5}$ concentrations in micrograms per cubic meter ($\mu g/m^3$) in 2028, 2030, and 2035 are shown in the colored column labeled "baseline" in the Figure 6-1 heat map. Concentrations in the "baseline" columns represent the total estimated $PM_{2.5}$ exposure burden averaged over the 12-month calendar year and are colored to visualize differences more easily in average concentrations (lighter blue coloring representing smaller average concentrations and darker blue coloring representing larger average concentrations). Average national disparities observed in the baseline of this rule are similar to those described by recent rules (e.g., the Final PM NAAQS), that is, populations with national average $PM_{2.5}$ concentrations higher than the reference population ordered from most to least difference were: residents of HOLC Grade D (i.e., redlined) census tracts, linguistically isolated, residents of HOLC Grade A-C (i.e., not redlined) census tracts, Hispanic individuals, Asian individuals, those without a high school diploma, Black individuals, below the poverty line, the unemployed, and the uninsured. Average national disparities observed in the baseline of this rule are generally consistent across the three future years and similar to those described by recent rules (e.g., the Final PM NAAQS).

For all three future years evaluated, there were no discernable $PM_{2.5}$ changes under the final regulatory option for any population analyzed when showing concentrations out to the hundredths digit, reiterating the small magnitude of national average $PM_{2.5}$ changes.

The national-level assessment of $PM_{2.5}$ before and after implementation of this final rulemaking suggests that while EJ exposure disparities are present in the pre-policy scenario, EJ exposure concerns are not likely created or exacerbated by the rule for the population groups evaluated, due to the small magnitude of the $PM_{2.5}$ concentration reductions. It is also important to note that at the national-level the $PM_{2.5}$ concentrations before and after implementation for all three future years evaluated the concentrations for each demographic group are below the recently revised standard of 9 µg/m^3.[106]



Group	Population	2028		2030		2035	
		Baseline	Absolute Reductions	Baseline	Absolute Reductions	Baseline	Absolute Reductions
Reference	Reference (0-99)	7.16	0.00	7.11	0.00	7.08	0.00
Race	American Indian (0-99)	6.69	0.00	6.66	0.00	6.64	0.00
	Asian (0-99)	7.73	0.00	7.67	0.00	7.62	0.00
	Black (0-99)	7.41	0.00	7.35	0.00	7.29	0.00
	White (0-99)	7.07	0.00	7.02	0.00	7.00	0.00
Ethnicity	Hispanic (0-99)	7.94	0.00	7.90	0.00	7.85	0.00
	Non-Hispanic (0-99)	6.94	0.00	6.89	0.00	6.85	0.00
Educational Attainment	Less educated (>24; no HS)	7.49	0.00	7.44	0.00	7.43	0.00
	More educated (>24: HS or more)	7.06	0.00	7.01	0.00	6.99	0.00
Employment Status	Employed (0-99)	7.15	0.00	7.10	0.00	7.07	0.00
	Not in the labor force (0-99)	7.16	0.00	7.11	0.00	7.08	0.00
	Unemployed (0-99)	7.31	0.00	7.26	0.00	7.24	0.00
Insurance Status	Insured (0-64)	7.20	0.00	7.15	0.00	7.12	0.00
	Uninsured (0-64)	7.27	0.00	7.23	0.00	7.20	0.00
Linquistic Isolation	English < well (0-99)	8.09	0.00	8.05	0.00	8.04	0.00
	English well or better (0-99)	7.11	0.00	7.06	0.00	7.04	0.00
Life Expectancy	Bottom 25% life expectancy (0-99)	7.20	0.00	7.13	0.00	7.10	0.00
	Life expectancy data unavailable (0-99)	7.11	0.00	7.07	0.00	7.04	0.00
	Top 75% life expectancy (0-99)	7.15	0.00	7.10	0.00	7.08	0.00
Poverty Status	<Poverty line (0-99)	7.33	0.00	7.28	0.00	7.25	0.00
	>Poverty line (0-99)	7.12	0.00	7.08	0.00	7.05	0.00
Redlined Areas	HOLC Grade D (0-99)	8.20	0.00	8.15	0.00	8.12	0.00
	HOLC Grades A-C (0-99)	7.95	0.00	7.90	0.00	7.86	0.00
	Not Graded by HOLC (0-99)	6.99	0.00	6.94	0.00	6.92	0.00
Tribal Land Designation	Not Tribal land (0-99)	7.16	0.00	7.11	0.00	7.09	0.00
	Tribal land (0-99)	6.63	0.00	6.58	0.00	6.53	0.00
Ages	Adults (18-64)	7.20	0.00	7.15	0.00	7.13	0.00
	Children (0-17)	7.22	0.00	7.17	0.00	7.14	0.00
	Older Adults (65-99)	6.94	0.00	6.90	0.00	6.89	0.00
Sex	Females (0-99)	7.17	0.00	7.12	0.00	7.09	0.00
	Males (0-99)	7.14	0.00	7.10	0.00	7.07	0.00

Figure 6-1 Heat Map of the National Average PM$_{2.5}$ Concentrations in the Baseline and Reductions in Concentrations Due to the Final Regulatory Option Across Demographic Groups in 2028, 2030, and 2035 (µg/m^3)

6.5.2.2 State Aggregated Results

We also assess PM$_{2.5}$ concentration reductions by state and demographic population in 2028, 2030, and 2035 for the 48 states in the contiguous U.S, for the final rule.

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[106] See *https://www.epa.gov/system/files/documents/2024-02/pm-naaqs-final-frn-pre-publication.pdf*.

The magnitude of state-level $PM_{2.5}$ concentration changes under the final regulatory option is not discernable out to the hundredths digit, reiterating the small magnitude of state-level average $PM_{2.5}$ changes. The small magnitude of differential $PM_{2.5}$ exposure impacts expected by the final rule is not likely to exacerbate or mitigate EJ concerns within individual states.

6.5.2.3 Distributional Results

We also assess the cumulative proportion of each population exposed to ascending levels of $PM_{2.5}$ concentration changes across the contiguous U.S. Results allow evaluation of what percentage of each subpopulation (e.g., Hispanics) in the contiguous U.S. experience what change in $PM_{2.5}$ concentrations compared to what percentage of the overall reference group (i.e., the total population of contiguous U.S.) experiences similar concentration changes from EGU emission changes under the final regulatory option in 2028, 2030, and 2035.

This distributional EJ analysis is also subject to additional uncertainties related to more highly resolved input parameters and additional assumptions. For example, this analysis does not account for potential difference in underlying susceptibility, vulnerability, or risk factors across populations to $PM_{2.5}$ exposure. Nor could we include information about differences in other factors that could affect the likelihood of adverse impacts (e.g., exercise patterns) across groups. Therefore, this analysis should not be used to assert that there are meaningful differences in $PM_{2.5}$ exposure impacts associated with either the baseline or the rule across population groups.

As the baseline scenario is similar to that described by other RIAs, we focus on the $PM_{2.5}$ changes due to this final rulemaking. Distributions of 12-km gridded $PM_{2.5}$ concentration changes from EGU control strategies of affected facilities analyzed for the years 2028, 2030, and 2035 were evaluated.

The vast majority of $PM_{2.5}$ concentration changes for each population distribution round to 0.00 $\mu g/m^3$ under the final regulatory option for all three future years analyzed. Therefore, there are no discernable differences in impacts in the distributional analyses of $PM_{2.5}$ concentration changes under the final regulatory option, which provides additional evidence that the final rule is not likely to exacerbate or mitigate EJ $PM_{2.5}$ exposure concerns for population groups evaluated.

6.5.3 Ozone EJ Exposure Analysis

To evaluate the potential for EJ concerns among potentially vulnerable populations resulting from exposure to ozone under the baseline and final rule, we characterize the projected distribution of ozone exposures both prior to and following implementation of the final rule in 2028, 2030, and 2035.

As this analysis is based on the same ozone spatial fields as the benefits assessment (see Appendix A for a discussion of the spatial fields), it is subject to similar types of uncertainty (see Section 4.3.8 for a discussion of the uncertainty). In addition to the small magnitude of differential ozone concentration changes associated with this final rulemaking when comparing across demographic populations, a particularly germane limitation is that ozone, being a secondary pollutant, is the byproduct of complex atmospheric chemistry such that direct linkages cannot be made between specific affected facilities and downwind ozone concentration changes based on available air quality modeling.

Ozone concentration and exposure metrics can take many forms, although only a small number are commonly used. The analysis presented here is based on the average April-September warm season maximum daily eight-hour average ozone concentrations (AS-MO3), consistent with the health impact functions used in the benefits assessment (Section 4). As developing spatial fields is time and resource intensive, the same spatial fields used for the benefits analysis were also used for the ozone exposure analysis performed here to assess EJ impacts.

The construct of the AS-MO3 ozone metric used for this analysis should be kept in mind when attempting to relate the results presented here to the ozone NAAQS and when interpreting the confidence in the association between exposures and health effects. Specifically, the seasonal average ozone metric used in this analysis is not constructed in a way that directly relates to NAAQS design values, which are based on daily maximum eight-hour concentrations.[107] Thus, AS-MO3 values reflecting seasonal *average* concentrations well below the level of the NAAQS at a particular location do not necessarily indicate that the location does not experience any *daily*

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[107] Level of 70 ppb with an annual fourth-highest daily maximum eight-hour concentration, averaged over three years.

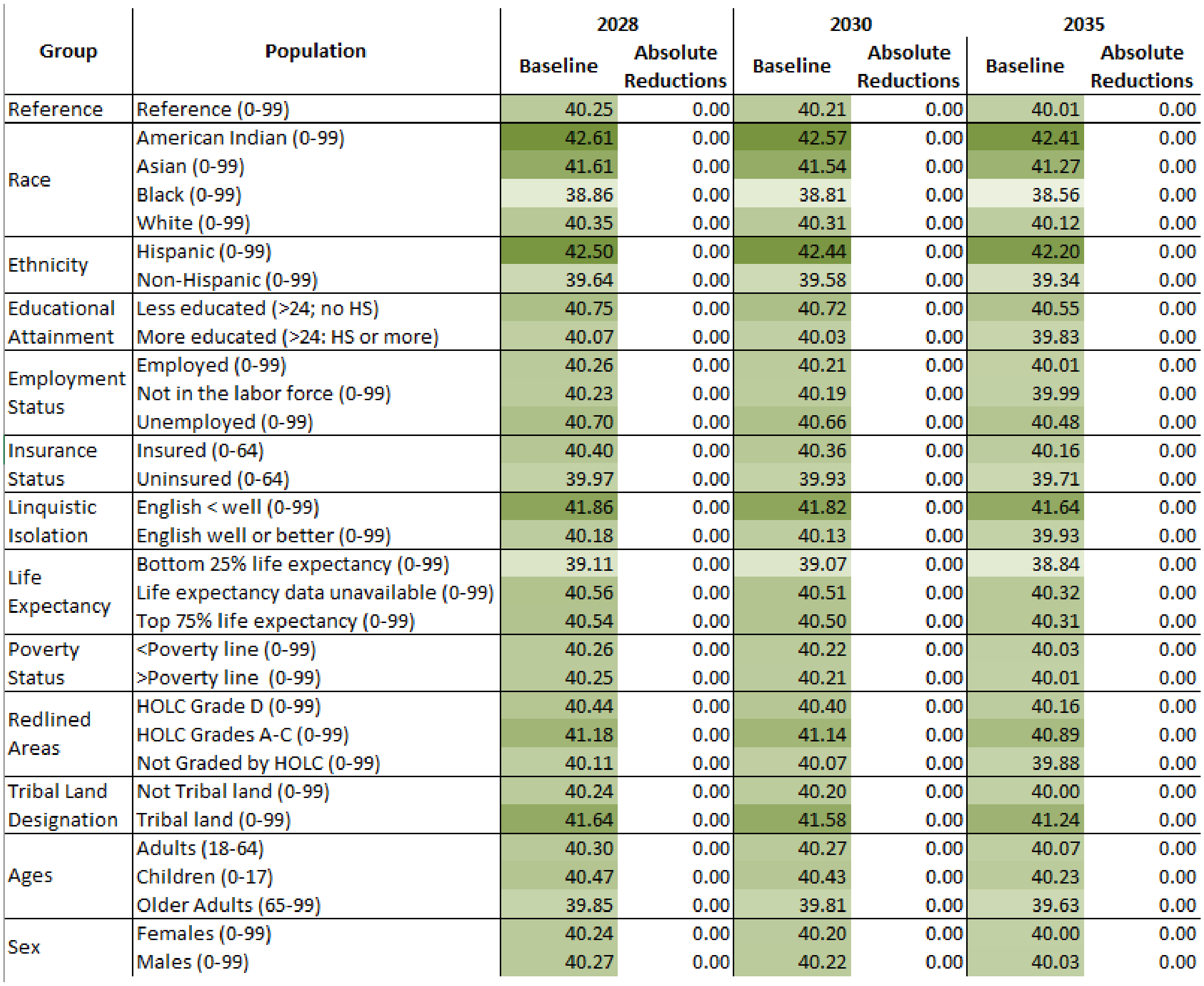
(eight-hour) exceedances of the ozone NAAQS. Relatedly, EPA is confident that reducing the highest ambient ozone concentrations will result in substantial improvements in public health, including reducing the risk of ozone-associated mortality. However, the Agency is less certain about the public health implications of changes in relatively low ambient ozone concentrations. Most health studies rely on a metric such as the warm-season average ozone concentration; as a result, EPA typically utilizes air quality inputs such as the AS-MO3 spatial fields in the benefits assessment, and we judge them also to be the best available air quality inputs for this EJ ozone exposure assessment.

6.5.3.1 National Aggregated Results

National average baseline ozone concentrations in ppb in 2028, 2030, and 2035 are shown in the colored column labeled “baseline” in the heat map (Figure 6-2). Concentrations in the “baseline” columns represent the total estimated daily eight-hour maximum ozone exposure burden averaged over the six-month April-September ozone season and are colored to visualize differences more easily in average concentrations, with lighter green coloring representing smaller average concentrations and darker green coloring representing larger average concentrations. Populations with national average ozone concentrations higher than the reference population ordered from most to least difference were: American Indian individuals, Hispanic individuals, those who are linguistically isolated, residents of Tribal Lands, Asian individuals, residents of HOLC Grades A-C (i.e., not redlined) census tracts, those without a high school diploma, the unemployed, populations with higher life expectancy or with life expectancy data unavailable, children, residents of HOLC Grade D (i.e., redlined) census tracts, and the insured. Average national disparities observed in the baseline of this rule are fairly consistent across the three future years and similar to those described by recent rules (e.g., the RIA for the Final GNP).

For all three future years evaluated, there were no discernable ozone changes under the final rule for any population analyzed when showing concentrations out to the hundredths digit, reiterating the small magnitude of national average ozone changes.

The national-level assessment of ozone burden concentrations in the baseline and ozone exposure changes due to the final rule suggests that while EJ exposure disparities are present in the pre-policy scenario, EJ exposure concerns are not likely created or exacerbated by the rule for the population groups evaluated, due to the small magnitude of the ozone concentration changes. Note that while we were able to compare the annual average $PM_{2.5}$ concentrations to the newly revised NAAQS, the estimated ozone impacts in terms of annual average change are difficult to compare to the ozone NAAQS as the annual fourth-highest daily maximum 8-hour concentration.



Group	Population	2028		2030		2035	
		Baseline	Absolute Reductions	Baseline	Absolute Reductions	Baseline	Absolute Reductions
Reference	Reference (0-99)	40.25	0.00	40.21	0.00	40.01	0.00
Race	American Indian (0-99)	42.61	0.00	42.57	0.00	42.41	0.00
	Asian (0-99)	41.61	0.00	41.54	0.00	41.27	0.00
	Black (0-99)	38.86	0.00	38.81	0.00	38.56	0.00
	White (0-99)	40.35	0.00	40.31	0.00	40.12	0.00
Ethnicity	Hispanic (0-99)	42.50	0.00	42.44	0.00	42.20	0.00
	Non-Hispanic (0-99)	39.64	0.00	39.58	0.00	39.34	0.00
Educational Attainment	Less educated (>24; no HS)	40.75	0.00	40.72	0.00	40.55	0.00
	More educated (>24: HS or more)	40.07	0.00	40.03	0.00	39.83	0.00
Employment Status	Employed (0-99)	40.26	0.00	40.21	0.00	40.01	0.00
	Not in the labor force (0-99)	40.23	0.00	40.19	0.00	39.99	0.00
	Unemployed (0-99)	40.70	0.00	40.66	0.00	40.48	0.00
Insurance Status	Insured (0-64)	40.40	0.00	40.36	0.00	40.16	0.00
	Uninsured (0-64)	39.97	0.00	39.93	0.00	39.71	0.00
Linquistic Isolation	English < well (0-99)	41.86	0.00	41.82	0.00	41.64	0.00
	English well or better (0-99)	40.18	0.00	40.13	0.00	39.93	0.00
Life Expectancy	Bottom 25% life expectancy (0-99)	39.11	0.00	39.07	0.00	38.84	0.00
	Life expectancy data unavailable (0-99)	40.56	0.00	40.51	0.00	40.32	0.00
	Top 75% life expectancy (0-99)	40.54	0.00	40.50	0.00	40.31	0.00
Poverty Status	<Poverty line (0-99)	40.26	0.00	40.22	0.00	40.03	0.00
	>Poverty line (0-99)	40.25	0.00	40.21	0.00	40.01	0.00
Redlined Areas	HOLC Grade D (0-99)	40.44	0.00	40.40	0.00	40.16	0.00
	HOLC Grades A-C (0-99)	41.18	0.00	41.14	0.00	40.89	0.00
	Not Graded by HOLC (0-99)	40.11	0.00	40.07	0.00	39.88	0.00
Tribal Land Designation	Not Tribal land (0-99)	40.24	0.00	40.20	0.00	40.00	0.00
	Tribal land (0-99)	41.64	0.00	41.58	0.00	41.24	0.00
Ages	Adults (18-64)	40.30	0.00	40.27	0.00	40.07	0.00
	Children (0-17)	40.47	0.00	40.43	0.00	40.23	0.00
	Older Adults (65-99)	39.85	0.00	39.81	0.00	39.63	0.00
Sex	Females (0-99)	40.24	0.00	40.20	0.00	40.00	0.00
	Males (0-99)	40.27	0.00	40.22	0.00	40.03	0.00

Figure 6-2 Heat Map of the National Average Ozone Concentrations in the Baseline and Reductions in Concentrations under the Final Rule Across Demographic Groups in 2028, 2030, and 2035 (ppb)

6.5.3.2 State Aggregated Results

We also provide ozone concentration reductions by state and demographic population in 2028, 2030, and 2035 for the 48 states in the contiguous U.S, for the final regulatory option

(Figure 6-3). In this heat map, dark blue indicates larger ozone reductions, with demographic groups shown as rows and each state as a column.

The magnitude of state-level ozone concentration changes under the final regulatory option is very small, with the vast majority of state-level ozone concentrations changes not discernable out to the hundredths digit. State-level average populations that are projected to experience reductions in ozone concentrations by up to 0.01 ppb are residents of HOLC Grade D (i.e., redlined) census tracts and Black individuals in Arkansas (AR), and most population groups in North Dakota (ND). Only state-level average reductions in ozone concentrations were observed for populations in 2028. The small magnitude of differential ozone exposure impacts expected by the final rule is not likely to exacerbate or mitigate EJ concerns within individual states.

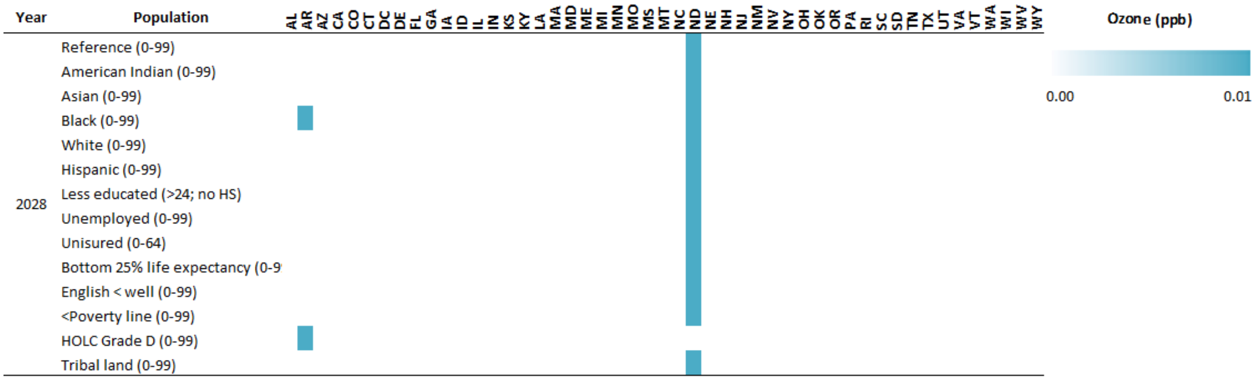


Figure 6-3 Heat Map of the State Average Ozone Concentrations Reductions (Green) and Increases (Red) under the Final Rule Across Demographic Groups in 2028 (ppb)

6.5.3.3 Distributional Results

We also assess the cumulative proportion of each population exposed to ascending levels of ozone concentration changes across the contiguous U.S. Results allow evaluation of what percentage of each subpopulation (e.g., Hispanic individuals) in the contiguous U.S. experience what change in ozone concentrations compared to what percentage of the overall reference group (i.e., the total population of contiguous U.S.) experiences similar concentration changes from EGU emission changes under the final regulatory option in 2028, 2030, and 2035.

This distributional EJ analysis is also subject to additional uncertainties related to more highly resolved input parameters and additional assumptions. For example, this analysis does not account for potential difference in underlying susceptibility, vulnerability, or risk factors across populations expected to experience post-policy ozone exposure changes. Nor could we include information about differences in other factors that could affect the likelihood of adverse impacts (e.g., exercise patterns) across groups. Therefore, this analysis should not be used to assert that there are meaningful differences in ozone exposures impacts in either the baseline or the rule across population groups.

As the baseline scenario is similar to that described by other RIAs, we focus on the ozone changes due to this final rulemaking. Distributions of 12-km gridded ozone concentration changes from EGU control strategies of affected facilities under the final rule were evaluated.

The vast majority of ozone concentration changes round to 0.00 ppb under the final regulatory option for all three future years analyzed. Therefore, there are no discernable differences in impacts in the distribution of ozone concentration changes across population demographics under the final regulatory option. This also provides additional evidence that the final rule is not likely to exacerbate or mitigate EJ ozone exposure concerns for population groups evaluated.

6.6 GHG Impacts on Environmental Justice and other Populations of Concern

In the 2009 Endangerment Finding, the Administrator considered how climate change threatens the health and welfare of the U.S. population. As part of that consideration, she also considered risks to people of color and low-income individuals and communities, finding that certain parts of the U.S. population may be especially vulnerable based on their characteristics or circumstances. These groups include economically and socially disadvantaged communities; individuals at vulnerable life stages, such as the elderly, the very young, and pregnant or nursing women; those already in poor health or with comorbidities; persons with disabilities; those experiencing homelessness, mental illness, or substance abuse; and Indigenous or other populations dependent on one or limited resources for subsistence due to factors including but not limited to geography, access, and mobility.

Scientific assessment reports produced over the past decade by the U.S. Global Change Research Program (USGCRP), the IPCC, the National Research Council, and the National Academies of Science, Engineering, and Medicine add more evidence that the impacts of climate change raise potential EJ concerns (IPCC, 2018; National Academies, 2017; National Research

Council, 2011; Oppenheimer et al., 2014; Porter et al., 2014; Smith et al., 2014; U.S. EPA, 2021; USGCRP, 2016, 2018). These reports conclude that less-affluent, traditionally marginalized, and predominantly non-White communities can be especially vulnerable to climate change impacts because they tend to have limited resources for adaptation, are more dependent on climate-sensitive resources such as local water and food supplies or have less access to social and information resources. Some communities of color, specifically populations defined jointly by ethnic/racial characteristics and geographic location (e.g.*,* African-American, Black, and Hispanic/Latino communities; individuals who identify as Native American, particularly those living on tribal lands and Alaska Natives), may be uniquely vulnerable to climate change health impacts in the U.S., as discussed below. In particular, the 2016 scientific assessment on the *Impacts of Climate Change on Human Health* found with high confidence that vulnerabilities are place- and time-specific, lifestages and ages are linked to immediate and future health impacts, and social determinants of health are linked to greater extent and severity of climate change-related health impacts (USGCRP, 2016).

Per the Fourth National Climate Assessment (NCA4), "Climate change affects human health by altering exposures to heat waves, floods, droughts, and other extreme events; vector-, food- and waterborne infectious diseases; changes in the quality and safety of air, food, and water; and stresses to mental health and well-being" (Ebi et al., 2018). Many health conditions such as cardiopulmonary or respiratory illness and other health impacts are associated with and exacerbated by an increase in GHGs and climate change outcomes, which is problematic as these diseases occur at higher rates within vulnerable communities. Importantly, negative public health outcomes include those that are physical in nature, as well as mental, emotional, social, and economic.

The scientific assessment literature, including the aforementioned reports, demonstrates that there are myriad ways in which these populations may be affected at the individual and community levels. Individuals face differential exposure to criteria pollutants, in part due to the proximities of highways, trains, factories, and other major sources of pollutant-emitting sources to less-affluent residential areas. Outdoor workers, such as construction or utility crews and agricultural laborers, who frequently are comprised of already at-risk groups, are exposed to poor air quality and extreme temperatures without relief. Furthermore, people in communities with EJ concerns face greater housing, clean water, and food insecurity and bear disproportionate and adverse economic impacts and health burdens associated with climate change effects. They have less or limited access to healthcare and affordable, adequate health or homeowner insurance (USGCRP, 2016). Finally, resiliency and adaptation are more difficult for economically vulnerable communities; these communities have less liquidity, individually and collectively, to move or to make the types of infrastructure or policy changes to limit or reduce the hazards they face. They frequently are less able to self-advocate for resources that would otherwise aid in building resilience and hazard reduction and mitigation.

The assessment literature cited in EPA's 2009 and 2016 Endangerment and Cause or Contribute Findings, as well as *Impacts of Climate Change on Human Health,* also concluded that certain populations and life stages, including children, are most vulnerable to climate-related health effects (USGCRP, 2016). The assessment literature produced from 2016 to the present strengthens these conclusions by providing more detailed findings regarding related vulnerabilities and the projected impacts youth may experience. These assessments – including the Fourth National Climate Assessment (USGCRP, 2018) and *The Impacts of Climate Change on Human Health in the United States* (USGCRP, 2016) – describe how children's unique physiological and developmental factors contribute to making them particularly vulnerable to climate change. Impacts to children are expected from heat waves, air pollution, infectious and waterborne illnesses, and mental health effects resulting from extreme weather events (USGCRP, 2016). In addition, children are among those especially susceptible to allergens, as well as health effects associated with heat waves, storms, and floods. Additional health concerns may arise in low-income households, especially those with children, if climate change reduces food availability and increases prices, leading to food insecurity within households. More generally, these reports note that extreme weather and flooding can cause or exacerbate poor health outcomes by affecting mental health because of stress; contributing to or worsening existing conditions, again due to stress or also as a consequence of exposures to water and air pollutants; or by impacting hospital and emergency services operations (Ebi et al., 2018). Further, in urban areas in particular, flooding can have significant economic consequences due to effects on infrastructure, pollutant exposures, and drowning dangers. The ability to withstand and recover from flooding is dependent in part on the social vulnerability of the affected population and individuals experiencing an event (National Academy of Sciences, 2019). In addition, children are among those especially susceptible to allergens, as well as health effects associated with heat waves, storms, and floods. Additional health concerns may arise in low-income households, especially those with children, if climate change reduces food availability and increases prices, leading to food insecurity within households.

The Impacts of Climate Change on Human Health also found that some communities of color, low-income groups, people with limited English proficiency, and certain immigrant groups (especially those who are undocumented) are subject to many factors that contribute to vulnerability to the health impacts of climate change (USGCRP, 2016). While difficult to isolate from related socioeconomic factors, race appears to be an important factor in vulnerability to climate-related stress, with elevated risks for mortality from high temperatures reported for Black or African American individuals compared to White individuals after controlling for factors such as air conditioning use. Moreover, people of color are disproportionately more exposed to air pollution based on where they live, and disproportionately vulnerable due to higher baseline prevalence of underlying diseases such as asthma. As explained earlier, climate change can exacerbate local air pollution conditions, so this increase in air pollution is expected to have disproportionate and adverse effects on these communities. Locations with greater health threats include urban areas (due to, among other factors, the "heat island" effect where built infrastructure and lack of green spaces increases local temperatures), areas where airborne allergens and other air pollutants already occur at higher levels, and communities that have experienced depleted water supplies or vulnerable energy and transportation infrastructure.

The 2021 EPA report on climate change and social vulnerability examined four socially vulnerable groups (individuals who are low income, minority, without high school diplomas, and/or 65 years and older) and their exposure to several different climate impacts (air quality, coastal flooding, extreme temperatures, and inland flooding) (U.S. EPA, 2021). This report found that Black and African-American individuals were 40 percent more likely to currently live in areas with the highest projected increases in mortality rates due to climate-driven changes in extreme temperatures, and 34 percent more likely to live in areas with the highest projected increases in childhood asthma diagnoses due to climate-driven changes in particulate air pollution. The report found that Hispanic and Latino individuals are 43 percent more likely to live in areas with the highest projected labor hour losses in weather-exposed industries due to climate-driven warming, and 50 percent more likely to live in coastal areas with the highest projected increases in traffic delays due to increases in high-tide flooding. The report found that

American Indian and Alaska Native individuals are 48 percent more likely to live in areas where the highest percentage of land is projected to be inundated due to sea level rise, and 37 percent more likely to live in areas with high projected labor hour losses. Asian individuals were found to be 23 percent more likely to live in coastal areas with projected increases in traffic delays from high-tide flooding. Persons with low income or no high school diploma are about 25 percent more likely to live in areas with high projected losses of labor hours, and 15 percent more likely to live in areas with the highest projected increases in asthma due to climate-driven increases in particulate air pollution, and in areas with high projected inundation due to sea level rise.

In a more recent 2023 report, *Climate Change Impacts on Children's Health and Well-Being in the U.S.,* EPA considered the degree to which children's health and well-being may be impacted by five climate-related environmental hazards—extreme heat, poor air quality, changes in seasonality, flooding, and different types of infectious diseases (U.S. EPA, 2023). The report found that children's academic achievement is projected to be reduced by 4–7 percent per child, as a result of moderate and higher levels of warming, impacting future income levels. The report also projects increases in the numbers of annual emergency department visits associated with asthma, and that the number of new asthma diagnoses increases by 4–11 percent due to climate-driven increases in air pollution relative to current levels. In addition, more than 1 million children in coastal regions are projected to be temporarily displaced from their homes annually due to climate-driven flooding, and infectious disease rates are similarly anticipated to rise, with the number of new Lyme disease cases in children living in 22 states in the eastern and midwestern U.S. increasing by approximately 3,000–23,000 per year compared to current levels. Overall, the report confirmed findings of broader climate science assessments that children are uniquely vulnerable to climate-related impacts and that in many situations, children in the U.S. who identify as Black, Indigenous, and People of Color, are limited English-speaking, do not have health insurance, or live in low-income communities may be disproportionately more exposed to the most severe adverse impacts of climate change.

Indigenous communities face disproportionate and adverse risks from the impacts of climate change, particularly those communities impacted by degradation of natural and cultural resources within established reservation boundaries and threats to traditional subsistence lifestyles. Indigenous communities whose health, economic well-being, and cultural traditions depend upon the natural environment will likely be affected by the degradation of ecosystem goods and services associated with climate change. The IPCC indicates that losses of customs and historical knowledge may cause communities to be less resilient or adaptable (Porter et al., 2014). The NCA4 (2018) noted that while Indigenous peoples are diverse and will be impacted by the climate changes universal to all Americans, there are several ways in which climate change uniquely threatens Indigenous peoples' livelihoods and economies (Jantarasami et al., 2018; USGCRP, 2018). In addition, as noted in the following paragraph, there can be institutional barriers (including policy-based limitations and restrictions) to their management of water, land, and other natural resources that could impede adaptive measures.

For example, Indigenous agriculture in the Southwest is already being adversely affected by changing patterns of flooding, drought, dust storms, and rising temperatures leading to increased soil erosion, irrigation water demand, and decreased crop quality and herd sizes. The Confederated Tribes of the Umatilla Indian Reservation in the Northwest have identified climate risks to salmon, elk, deer, roots, and huckleberry habitat. Housing and sanitary water supply infrastructure are vulnerable to disruption from extreme precipitation events. Native Americans' ability to respond to these conditions is impeded by limitations imposed by statutes including the Dawes Act of 1887 and the Indian Reorganization Act of 1934, which ultimately restrict Indigenous peoples' autonomy regarding land-management decisions through Federal trusteeship of certain tribal lands and mandated Federal oversight of these peoples' management decisions. Additionally, NCA4 noted that Indigenous peoples generally are subjected to institutional racism effects, such as poor infrastructure, diminished access to quality healthcare, and greater risk of exposure to pollutants. Consequently, Native Americans often have disproportionately higher rates of asthma, cardiovascular disease, Alzheimer's disease, diabetes, and obesity. These health conditions and related effects (disorientation, heightened exposure to $PM_{2.5}$, etc.) can all contribute to increased vulnerability to climate-driven extreme heat and air pollution events, which also may be exacerbated by stressful situations, such as extreme weather events, wildfires, and other circumstances.

NCA4 and IPCC's Fifth Assessment Report also highlighted several impacts specific to Alaskan Indigenous Peoples (Porter et al., 2014). Coastal erosion and permafrost thaw will lead to more coastal erosion, rendering winter travel riskier and exacerbating damage to buildings, roads, and other infrastructure—impacts on archaeological sites, structures, and objects that will lead to a loss of cultural heritage for Alaska's Indigenous people. In terms of food security, the NCA4 discussed reductions in suitable ice conditions for hunting, warmer temperatures impairing the use of traditional ice cellars for food storage, and declining shellfish populations due to warming and acidification. While the NCA4 also noted that climate change provided more opportunity to hunt from boats later in the fall season or earlier in the spring, the assessment found that the net impact was an overall decrease in food security.

6.7 Summary

As with all EJ analyses, data limitations make it quite possible that disparities may exist that our analysis did not identify. This is especially relevant for potential EJ characteristics, environmental impacts, and more granular spatial resolutions that were not evaluated. For example, here we provide qualitative EJ assessment of ozone and $PM_{2.5}$ concentration changes from this rule but can only qualitatively discuss EJ impacts of CO_2 emission reductions. Therefore, this analysis is only a partial representation of the distributions of potential impacts. Additionally, EJ concerns for each rulemaking are unique and should be considered on a case-by-case basis, so results similar to those presented here should not be assumed for other rulemakings.

For the rule, we quantitatively evaluate the proximity of affected facilities populations of potential EJ concern (Section 6.4) and the potential for disproportionate pre- and policy-policy $PM_{2.5}$ and ozone exposures across different demographic groups (Section 6.5). As exposure results generated as part of the 2020 Residual Risk analysis were below both the presumptive acceptable cancer risk threshold and the noncancer health benchmarks, and this final regulation should still reduce exposure to HAP, there are no 'disproportionate and adverse effects' of potential EJ concern. Therefore, we did not perform a quantitative EJ assessment of HAP risk. Each of these analyses presented depend on mutually exclusive assumptions, was performed to answer separate questions, and is associated with unique limitations and uncertainties.

Baseline demographic proximity analyses provide information as to whether there may be potential EJ concerns associated with local environmental stressors such as local NO_2 and SO_2 emitted from sources affected by the regulatory action, traffic, or noise for certain population groups of concern in the baseline (Section 6.4). The baseline demographic proximity analyses examined the demographics of populations living within 10 km of the following sources: lignite-fired coal plants with units potentially impacted by the Hg standard revision and coal plants with units potentially impacted by the fPM standard revision. The proximity demographic analysis indicates that on average, the population living within 10 km of coal plants potentially impacted by the fPM standards shas a higher percentage of people living below two times the poverty level than the national average. In addition, on average the percentage of the Native American population living within 10 km of lignite-fired coal plants potentially impacted by Hg standard is higher than the national average. Relating these results to question 1 from Section 6.3, we conclude that there may be potential EJ concerns associated with directly emitted pollutants that are affected by the regulatory action (e.g., local NO_X or SO_2) for certain population groups of concern in the baseline (question 1). However, as proximity to affected facilities does not capture variation in baseline exposure across communities, nor does it indicate that any exposures or impacts will occur, these results should not be interpreted as a direct measure of exposure or impact.

While the demographic proximity analyses may appear to parallel the baseline analysis of nationwide ozone and $PM_{2.5}$ exposures in certain ways, the two should not be directly compared. The baseline ozone and $PM_{2.5}$ exposure assessments are in effect an analysis of total burden in the contiguous U.S., and include various assumptions, such as the implementation of promulgated regulations. It serves as a starting point for both the estimated ozone and $PM_{2.5}$ changes due to this final rule as well as a snapshot of air pollution concentrations in the near future. This final rule is also expected to reduce emissions of direct $PM_{2.5}$, NO_X, and SO_2 nationally throughout the year. Because NO_X and SO_2 are also precursors to secondary formation of ambient $PM_{2.5}$ and NO_X is a precursor to ozone formation, reducing these emissions would impact human exposure. Quantitative ozone and $PM_{2.5}$ exposure analyses can provide insight into all three EJ questions, so they are performed to evaluate potential disproportionate impacts of this rulemaking.

The baseline ozone and $PM_{2.5}$ exposure analyses respond to question 1 from EPA's EJ Technical Guidance document more directly than the proximity analyses, as they evaluate a form of the environmental stressor primarily affected by the regulatory action (Section 6.5). Baseline $PM_{2.5}$ and ozone exposure analyses show that certain populations, such as residents of redlined census tracts, those linguistically isolated, Hispanic individuals, Asian individuals, those without a high school diploma, and the unemployed may experience disproportionately higher ozone and

$PM_{2.5}$ exposures as compared to the national average. American Indian individuals, residents of Tribal Lands, populations with higher life expectancy or with life expectancy data unavailable, children, and insured populations may also experience disproportionately higher ozone concentrations than the reference group. Hispanic individuals, Black individuals, those below the poverty line, and uninsured populations may also experience disproportionately higher PM2.5 concentrations than the reference group. Therefore, there likely are potential EJ concerns associated with environmental stressors affected by the regulatory action for population groups of concern in the baseline.

Finally, we evaluate how the post-policy options of this final rulemaking are expected to differentially impact demographic populations, informing questions 2 and 3 from EPA's EJ Technical Guidance with regard to ozone and $PM_{2.5}$ exposure changes. Due to the small magnitude of the exposure changes across population demographics associated with the rulemaking relative to the magnitude of the baseline disparities, we infer that baseline disparities in ozone and $PM_{2.5}$ concentration burdens are likely to remain after implementation of the final regulatory option (question 2). Also, due to the very small differences in the magnitude of post-policy ozone and $PM_{2.5}$ exposure impacts across demographic populations, we do not find evidence that potential EJ concerns related to ozone or $PM_{2.5}$ exposures will be exacerbated or mitigated in the final regulatory option, compared to the baseline (question 3).

This EJ air quality analysis concludes that there are $PM_{2.5}$ and ozone exposure disparities across various populations in the pre-policy baseline scenario (EJ question 1) and infer that these disparities are likely to persist after promulgation of this final rulemaking (EJ question 2). This EJ assessment also suggests that this action will neither mitigate nor exacerbate $PM_{2.5}$ and ozone exposure disparities across populations of EJ concern analyzed (EJ question 3) at the national scale.

6.8 References

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COMPARISON OF BENEFITS AND COSTS

7.1 Introduction

This section presents the estimates of the projected benefits, costs, and net benefits associated with the final MATS review relative to baseline MATS requirements. There are potential benefits and costs that may result from this rule that have not been quantified or monetized. Due to current data and modeling limitations, quantified and monetized benefits from reducing Hg and non-Hg HAP metals emissions are not included in the monetized benefits presented here. We are also unable to quantify the potential benefits from the CEMS requirement. Due to data and modeling limitations, there are also still many categories of climate impacts and associated damages that are not reflected yet in the monetized climate benefits from reducing CO_2 emissions. For example, the modeling omits most of the consequences of changes in precipitation, damages from extreme weather events, the potential for nongradual damages from passing critical thresholds (e.g., tipping elements) in natural or socioeconomic systems, and non-climate mediated effects of GHG emissions (e.g., ocean acidification).

The projections indicate that the final rule results in 9,500 pounds of reductions in emissions of Hg as well as 5,400 tons of reductions in $PM_{2.5}$ across all run years. The final rule is projected to also reduce CO_2, SO_2, and NO_x by 650,000 tons, 770 tons, and 220 tons, respectively, and we estimate that the final rule will reduce at least 49 tons of non-Hg HAP metals. These reductions are composed of reductions in emissions of antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, nickel, and selenium.[108] Table 7-1 summarizes the total emissions reductions projected over the 2028 to 2037 analysis period.

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[108] The estimates on non-mercury HAP metals reductions were obtained my multiplying the ratio of non-mercury HAP metals to fPM by estimates of PM_{10} reductions under the rule, as we do not have estimates of fPM reductions using IPM, only PM_{10}. The ratios of non-mercury HAP metals to fPM were based on analysis of 2010 MATS Information Collection Request (ICR) data. As there may be substantially more fPM than PM_{10} reduced by the control techniques projected to be used under this rule, these estimates of non-mercury HAP metals reductions are likely underestimates. More detail on the estimated reduction in non-mercury HAP metals can be found in the docketed memorandum *Estimating Non-Hg HAP Metals Reductions for the 2024 Technology Review for the Coal-Fired EGU Source Category.*

Table 7-1 Cumulative Projected Emissions Reductions for the Final Rule, 2028 to 2037[a,b]

Pollutant	Emissions Reductions
Hg (pounds)	9,500
$PM_{2.5}$ (tons)	5,400
CO_2 (thousand tons)	650
SO_2 (tons)	770
NO_x (tons)	220
Non-Hg HAP metals (tons)	49

[a] Values rounded to two significant figures.

[b] Estimated reductions from model year 2028 are applied to 2028 and 2029, those from model year 2030 are applied to 2031 and 2032, and those from model year 2035 are applied to 2032 through 2037. These values are summed to generate total reduction figures.

The compliance costs reported in this RIA are not social costs, although in this analysis we use compliance costs as a proxy for social costs. We do not account for changes in costs and benefits due to changes in economic welfare of suppliers to the electricity market or to non-electricity consumers from those suppliers. Furthermore, costs due to interactions with pre-existing market distortions outside the electricity sector are omitted.

7.2 Methods

EPA calculated the PV of benefits, costs, and net benefits for the years 2028 through 2037, using 2, 3, and 7 percent end-of-period discount rates from the perspective of 2023. All dollars are in 2019 dollars. In addition to the final rule, we assess a less stringent alternative to the final requirements.

This calculation of a PV requires an annual stream of values for each year of the 2028 to 2037 timeframe. EPA used IPM to estimate cost and emission changes for the projection years 2028, 2030, and 2035. The year 2028 approximates the compliance year for the final requirements. In the IPM modeling for this RIA, the 2028 projection year is representative of 2028 and 2029, the 2030 projection year is representative of 2030 and 2031, and the 2035 projection year is representative of 2032 to 2037. Estimates of costs and emission changes in other years are determined from the mapping of projection years to the calendar years that they represent. Consequently, the cost and emission estimates from IPM in each projection year are applied to the years which it represents.[109]

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[109] Projected costs associated with the CEMS requirement are not based on IPM. For information on these cost estimates, see Section 3.

Health benefits are based on projection year emission estimates and also account for year-specific variables that influence the size and distribution of the benefits. These variables include population growth, income growth, and the baseline rate of death.[110] Climate benefits estimates are based on these projection year emission estimates, and also account for year-specific SC-CO_2 values.

EPA calculated the PV and EAV of costs, benefits, and net benefits over the 2028 through 2037 timeframe for the three regulatory options examined in this RIA. The EAV represents a flow of constant annual values that, had they occurred in each year from 2028 to 2037, would yield an equivalent present value. The EAV represents the value of a typical cost or benefit for each year of the analysis, in contrast to the year-specific estimates presented elsewhere for the snapshot years of 2028, 2030, and 2035.

7.3 Results

We first present net benefit analysis for the three years of detailed analysis, 2028, 2030, and 2035. Table 7-2, Table 7-3, and Table 7-4 present the estimates of the projected compliance costs, health benefits, climate benefits, and net benefits projected for the final rule. Table 7-5, Table 7-6, and Table 7-7 present results for the less stringent regulatory option.

The comparison of benefits and costs in PV and EAV terms for the final rule can be found in for the final regulatory option. Table 7-9 presents the results for the less stringent regulatory option. Estimates in the tables are presented as rounded values. Note the less stringent regulatory option only has unquantified benefits associated with requirements for PM CEMS. As a result, there are no quantified benefits associated with this regulatory option.

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[110] As these variables differ by year, the health benefit estimates vary by year, including when different years are based on the same IPM projection year emission estimate.

Table 7-2 Projected Net Benefits of the Final Rule in 2028 (millions of 2019 dollars)[a,b]

		Final Rule, 2028	
Health Benefits[c]	42	and	87
Climate Benefits[d]		14	
Total Benefits[e]	57	and	100
Compliance Costs		110	
Net Benefits	**-58**	**and**	**-13**

Non-Monetized Benefits[e]
Benefits from reductions of about 1000 pounds of Hg
Benefits from reductions of about 7 tons of non-Hg HAP metals
Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

[a] We focus results to provide a snapshot of projected benefits and costs in 2028, using the best available information to approximate social costs and social benefits recognizing uncertainties and limitations in those estimates.

[b] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

[c] Monetized air quality related benefits include those related to public health associated with reductions in $PM_{2.5}$ and ozone concentrations. For the presentational purposes of this table, the projected health benefits reported here are associated with several point estimates and are presented at a real discount rate of 2 percent. See Table 4-4 for the full range of monetized health benefit estimates.

[d] Monetized climate benefits are based on reductions in CO_2 emissions and are calculated using three different estimates of the social cost of carbon dioxide (SC-CO_2) (under 1.5 percent, 2 percent, and 2.5 percent near-term Ramsey discount rates). For the presentational purposes of this table, we show the climate benefits associated with the SC-CO_2 at the 2 percent near-term Ramsey discount rate. See Table 4-10 for the full range of monetized climate benefit estimates.

[e] Several categories of benefits remain unmonetized and are thus not directly reflected in the quantified benefit estimates in the table. Non-monetized benefits include benefits from reductions in Hg and non-Hg HAP metals emissions and from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring CEMS.

Table 7-3 Projected Net Benefits of the Final Rule in 2030 (millions of 2019 dollars)[a,b]

		Final Rule, 2030	
Health Benefits[c]	15	and	31
Climate Benefits[d]		-8.2	
Total Benefits[e]	7.3	and	22
Compliance Costs		120	
Net Benefits	**-110**	**and**	**-94**
		Non-Monetized Benefits[e]	
		Benefits from reductions of about 1000 pounds of Hg	
		Benefits from reductions of about 4 tons of non-Hg HAP metals	
		Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS	

[a] We focus results to provide a snapshot of projected benefits and costs in in 2030, using the best available information to approximate social costs and social benefits recognizing uncertainties and limitations in those estimates.

[b] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

[c] Monetized air quality related health benefits include those related to public health associated with reductions in $PM_{2.5}$ and ozone concentrations. For the presentational purposes of this table, the projected health benefits reported here are associated with several point estimates and are presented at a real discount rate of 2 percent. See Table 4-4 for the full range of monetized health benefit estimates.

[d] Monetized climate benefits are based on reductions in CO_2 emissions and are calculated using three different estimates of the social cost of methane (SC-CO_2) (under 1.5 percent, 2 percent, and 2.5 percent near-term Ramsey discount rates). For the presentational purposes of this table, we show the climate benefits associated with the SC-CO_2 at the 2 percent near-term Ramsey discount rate. See Table 4-10 for the full range of monetized climate benefit estimates.

[e] Several categories of benefits remain unmonetized and are thus not directly reflected in the quantified benefit estimates in the table. Non-monetized benefits include benefits from reductions in Hg and non-Hg HAP metals emissions and from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring CEMS.

Table 7-4 Projected Net Benefits of the Final Rule in 2035 (millions of 2019 dollars)[a,b]

	Final Rule, 2035		
Health Benefits[c]	10	and	18
Climate Benefits[d]		24	
Total Benefits[e]	34	and	42
Compliance Costs		95	
Net Benefits	**-61**	**and**	**-53**

Non-Monetized Benefits[e]
Benefits from reductions of about 900 pounds of Hg
Benefits from reductions of about 4 tons of non-Hg HAP metals
Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

[a] We focus results to provide a snapshot of projected benefits and costs in 2035, using the best available information to approximate social costs and social benefits recognizing uncertainties and limitations in those estimates.

[b] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

[c] Monetized air quality related health benefits include those related to public health associated with reductions in $PM_{2.5}$ and ozone concentrations. For the presentational purposes of this table, the projected health benefits reported here are associated with several point estimates and are presented at a real discount rate of 2 percent. See Table 4-4 for the full range of monetized health benefit estimates.

[d] Monetized climate benefits are based on reductions in CO_2 emissions and are calculated using three different estimates of the social cost of carbon dioxide (SC-CO_2) (under 1.5 percent, 2 percent, and 2.5 percent near-term Ramsey discount rates). For the presentational purposes of this table, we show the climate benefits associated with the SC-CO_2 at the 2 percent near-term Ramsey discount rate. See Table 4-10 for the full range of monetized climate benefit estimates.

[e] Several categories of benefits remain unmonetized and are thus not directly reflected in the quantified benefit estimates in the table. Non-monetized benefits include benefits from reductions in Hg and non-Hg HAP metals emissions and from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring CEMS.

Table 7-5 Projected Monetized Benefits, Costs, and Net Benefits of the Less Stringent Option in 2028 (millions of 2019 dollars) [a,b]

		Final Rule, 2028	
Health Benefits[c]	0	and	0
Climate Benefits[d]		0	
Total Benefits[e]	0	and	0
Compliance Costs		2.3	
Net Benefits	**-2.3**	**and**	**-2.3**

Non-Monetized Benefits
Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

[a] We focus results to provide a snapshot of projected benefits and costs in 2035, using the best available information to approximate social costs and social benefits recognizing uncertainties and limitations in those estimates.

[b] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

Table 7-6 Projected Monetized Benefits, Costs, and Net Benefits of the Less Stringent Option in 2030 (millions of 2019 dollars) [a,b]

		Final Rule, 2030	
Health Benefits[c]	0	and	0
Climate Benefits[d]		0	
Total Benefits[e]	0	and	0
Compliance Costs		2.3	
Net Benefits	**-2.3**	**and**	**-2.3**

Non-Monetized Benefits
Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

[a] We focus results to provide a snapshot of projected benefits and costs in 2035, using the best available information to approximate social costs and social benefits recognizing uncertainties and limitations in those estimates.

[b] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

Table 7-7 Projected Monetized Benefits, Costs, and Net Benefits of the Less Stringent Option in 2035 (millions of 2019 dollars)[a,b]

		Final Rule, 2035	
Health Benefits[c]	0	and	0
Climate Benefits[d]		0	
Total Benefits[e]	0	and	0
Compliance Costs		2.3	
Net Benefits	**-2.3**	**and**	**-2.3**

Non-Monetized Benefits
Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

[a] We focus results to provide a snapshot of projected benefits and costs in 2035, using the best available information to approximate social costs and social benefits recognizing uncertainties and limitations in those estimates.

[b] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

Table 7-8 Stream of Projected Monetized Benefits, Costs, and Net Benefits of the Final Rule, 2028 to 2037 (discounted to 2023, millions of 2019 dollars)[a]

		Health Benefits[b]		Climate Benefits[c,d]		Compliance Costs			Net Benefits[e]	
Year	**2%**	**3%**	**7%**	**2%**	**2%**	**3%**	**7%**	**2%**	**3%**	**7%**
2028	79	71	52	13	100	99	82	-12	-15	-16
2029	79	71	50	13	100	96	77	-10	-13	-13
2030	27	24	16	-7.1	100	95	73	-82	-78	-64
2031	27	24	16	-7.1	100	92	68	-80	-76	-60
2032	14	13	8	19	79	73	52	-46	-41	-24
2033	14	13	8	19	78	71	48	-44	-39	-21
2034	14	12	7.3	19	76	69	45	-43	-37	-19
2035	14	12	7.0	19	75	67	42	-41	-35	-16
2036	14	12	6.7	19	73	65	39	-40	-33	-14
2037	14	12.0	6.4	19	72	63	37	-39	-32	-11
		Health Benefits[b]		**Climate Benefits[c,d]**		**Compliance Costs**			**Net Benefits[e]**	
						Discount Rate				
	2%	**3%**	**7%**	**2%**	**2%**	**3%**	**7%**	**2%**	**3%**	**7%**
PV	**300**	**260**	**180**	**130**	**860**	**790**	**560**	**-440**	**-400**	**-260**
EAV	**33**	**31**	**25**	**14**	**96**	**92**	**80**	**-49**	**-47**	**-41**

Non-Monetized Benefits[e]
Benefits from reductions of about 900 to 1000 pounds of Hg annually
Benefits from reductions of about 4 to 7 tons of non-Hg HAP metals annually
Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

[a] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

[b] The estimated value of the air quality-related health benefits reported here are from Table 4-5, Table 4-6, and Table 4-7. Monetized benefits include those related to public health associated with reductions in $PM_{2.5}$ and ozone concentrations. For discussions of the uncertainty associated with these health benefits estimates, see Section 4.3.8.

[c] Monetized climate benefits are based on reductions in CO_2 emissions and are calculated using three different estimates of the social cost of carbon dioxide (SC-CO_2) (under 1.5 percent, 2 percent, and 2.5 percent near-term Ramsey discount rates). For the presentational purposes of this table, we show the climate benefits associated with the SC-CO_2 at the 2 percent near-term Ramsey discount rate. See Table 4-10 for the full range of monetized climate benefit estimates.

[d] The small increases and decreases in climate and health benefits and related EJ impacts result from very small changes in fossil dispatch and coal use relative to the baseline. For context, the projected increase in CO_2 emission of less than 40,000 tons in 2030 is roughly one percent of the emissions of a mid-size coal plant operating at availability (about 4 million tons).

[e] Several categories of benefits remain unmonetized and are thus not reflected in the table.

Table 7-9 Stream of Projected Monetized Benefits, Costs, and Net Benefits of the Less Stringent Option, 2028 to 2037 (millions of 2019 dollars, discounted to 2023)[a]

	Health Benefits			Climate Benefits	Compliance Costs			Net Benefits		
Year	**2%**	**3%**	**7%**	**2%**	**2%**	**3%**	**7%**	**2%**	**3%**	**7%**
2023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2024	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2025	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2026	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2027	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	0.0	0.0	0.0	0.0	2.1	2.0	1.7	-2.1	-2.0	-1.7
2029	0.0	0.0	0.0	0.0	2.1	2.0	1.6	-2.1	-2.0	-1.6
2030	0.0	0.0	0.0	0.0	2.0	1.9	1.5	-2.0	-1.9	-1.5
2031	0.0	0.0	0.0	0.0	2.0	1.9	1.4	-2.0	-1.9	-1.4
2032	0.0	0.0	0.0	0.0	2.0	1.8	1.3	-2.0	-1.8	-1.3
2033	0.0	0.0	0.0	0.0	1.9	1.7	1.2	-1.9	-1.7	-1.2
2034	0.0	0.0	0.0	0.0	1.9	1.7	1.1	-1.9	-1.7	-1.1
2035	0.0	0.0	0.0	0.0	1.9	1.6	1.0	-1.9	-1.6	-1.0
2036	0.0	0.0	0.0	0.0	1.8	1.6	1.0	-1.8	-1.6	-1.0
2037	0.0	0.0	0.0	0.0	1.8	1.6	0.9	-1.8	-1.6	-0.9

	Health Benefits			Climate Benefits	Compliance Costs			Net Benefits		
					Discount Rate					
	2%	**3%**	**7%**	**2%**	**2%**	**3%**	**7%**	**2%**	**3%**	**7%**
PV	**0.0**	**0.0**	**0.0**	**0.0**	**20**	**18**	**13**	**-20**	**-18**	**-13**
EAV	**0.0**	**0.0**	**0.0**	**0.0**	**2.2**	**2.1**	**1.8**	**-2.2**	**-2.1**	**-1.8**

Non-Monetized Benefits[b]

Benefits from the increased transparency, compliance assurance, and accelerated identification of anomalous emission anticipated from requiring PM CEMS

[a] Values have been rounded to two significant figures. Rows may not appear to add correctly due to rounding.

[b] Several categories of benefits remain unmonetized and are thus not reflected in the table.

The monetized estimates of benefits presented in this section are underestimated because important categories of benefits, including benefits from reducing Hg and non-Hg HAP metals emissions and the increased transparency, compliance assurance, and the potential emissions reductions from the accelerated identification of anomalous emissions anticipated from requiring PM CEMS, were not monetized in our analysis. Additionally, to the extent that the removal of the second definition of startup leads to actions that may otherwise not occur absent this final rule, there may be benefit and cost impacts we are unable to estimate. As a result, the estimates of compliance costs used in the net benefits analysis may provide an incomplete characterization of the true costs of the rule. We nonetheless consider these potential impacts in our evaluation of the net benefits of the rule.

7.4 Uncertainties and Limitations

Throughout the RIA, we considered several sources of uncertainty, both quantitatively and qualitatively, regarding the emissions reductions, benefits, and costs estimated for the final rule. We summarize the key elements of our discussions of uncertainty below.

Compliance costs: The IPM-projected annualized cost estimates of private compliance costs provided in this analysis are meant to show the increase in production (generating) costs to the power sector in response to the finalized requirements. As discussed in more detail in section 3.6, there are several key areas of uncertainty related to the electric power sector that are worth noting, including assumptions about electricity demand, natural gas supply and demand, longer-term planning by utilities, and assumptions about the cost and performance of controls. There are also uncertainties associated with the estimated costs for the CEMS requirement as well as associated with the potential costs of the removal of the startup definition if these amendments lead to actions by affected facilities that otherwise would not occur absent the finalized amendments.

Non-monetized benefits: Several categories of health, welfare, and climate benefits are not quantified in this RIA. These unquantified benefits are described in detail in Section 4. As noted above, EPA is unable to quantify and monetize the incremental potential benefits of requiring facilities to utilize CEMS rather than continuing to allow the use of quarterly testing, but the requirement has been considered qualitatively.

Monetized $PM_{2.5}$ and ozone-related benefits: The analysis of monetized $PM_{2.5}$ and ozone-related benefits described in Section 4.3 includes many data sources as inputs that are each subject to uncertainty. Input parameters include projected emissions inventories, projected compliance methods, air quality data from models (with their associated parameters and inputs), population data, population estimates, health effect estimates from epidemiology studies, economic data, and assumptions regarding the future state of the world (i.e., regulations, technology, and human behavior). When compounded, even small uncertainties can greatly influence the size of the total quantified benefits. Below are key uncertainties associated with estimating the number and value of $PM_{2.5}$ and ozone-related premature deaths. Additional detail regarding specific uncertainties associated with ozone health benefit estimates can be found in the Health Benefits TSD (U. S. EPA, 2023). A discussion of uncertainties and limitations related to the air quality modeling informing the $PM_{2.5}$ and ozone-related benefits analysis is presented in section 8.6

Monetized CO_2-related climate benefits: EPA considered the uncertainty associated with the SC-CO_2) estimates, which were used to calculate the monetized climate impacts of the changes in CO_2 emissions projected to result from this action. Section 4.4 provides a detailed discussion of the limitations and uncertainties associated with the SC-CO_2 estimates used in this analysis and describes ways in which the modeling addresses quantified sources of uncertainty.

7.5 References

U. S. EPA. (2023). *Air Quality Modeling Technical Support Document for Regulatory Impact Analysis of the Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review*. (EPA-454/R-23-007). Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards

APPENDIX A: AIR QUALITY MODELING

A.1 Introduction

As noted in Section 4, EPA used photochemical modeling to create air quality surfaces[111] that were then used in air pollution health benefits calculations of the final rule. The modeling-based surfaces captured air pollution impacts resulting from changes in NO_X, SO_2, and direct $PM_{2.5}$ emissions from EGUs. This appendix describes the source apportionment modeling and associated methods used to create air quality surfaces for the baseline scenario and the final rule scenario in three analytic years: 2028, 2030, and 2035. EPA created air quality surfaces for the following pollutants and metrics: annual average $PM_{2.5}$; April-September average of 8-hr daily maximum (MDA8) ozone (AS-MO3).

New ozone and PM source apportionment modeling outputs were created to support analyses in the RIAs for multiple final EGU rulemaking efforts. The basic methodology for determining air quality changes is the same as that used in the RIAs from multiple previous rules (U.S. EPA, 2019, 2020a, 2020b, 2021b, 2022a). EPA calculated baseline and final rule EGU emissions estimates of NO_X and SO_2 for all three analysis years using IPM (Section 3 of this RIA). EPA also used IPM outputs to estimate EGU emissions of $PM_{2.5}$ based on emission factors described in U.S. EPA (2021a). This appendix provides additional details on the source apportionment modeling simulations and the associated analysis used to create ozone and $PM_{2.5}$ air quality surfaces.

A.2 Air Quality Modeling Simulations

The air quality modeling utilized a 2016-based modeling platform which included meteorology and base year emissions from 2016 and projected future-year emissions for 2026 for all sectors other than EGUs and 2030 for EGUs. The air quality modeling included photochemical model simulations for a 2016 base year and a future year representing the combined 2026/2030 emissions described above to provide hourly concentrations of ozone and $PM_{2.5}$ component species nationwide. In addition, source apportionment modeling was performed for the future year to quantify the contributions to ozone from NO_X emissions and to $PM_{2.5}$ from NO_X, SO_2 and directly emitted $PM_{2.5}$ emissions from EGUs on a state-by-state and

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[111] "Air quality surfaces" refers to continuous gridded spatial fields using a 12 km grid-cell resolution.

fuel-type basis. As described below, the modeling results for 2016 and the future year, in conjunction with EGU emissions data for the baseline and the final rule in 2028, 2030, and 2035 were used to construct the air quality surfaces that reflect the influence of emissions changes between the baseline and the final rule in each year.

The air quality model simulations (i.e., model runs) were performed using the Comprehensive Air Quality Model with Extensions (CAMx) version 7.10[112] (Ramboll Environ, 2021). The nationwide modeling domain (i.e., the geographic area included in the modeling) covers all lower 48 states plus adjacent portions of Canada and Mexico using a horizontal grid resolution of 12 km shown in Figure A-1. CAMx requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, hourly emissions estimates and meteorological data, and initial and boundary concentrations. The meteorological data and the initial and boundary concentrations were identical to those described in U.S. EPA (2023a). Separate emissions inventories were prepared for the 2016 base year and the projected future year. All other inputs (i.e., meteorological fields, initial concentrations, ozone column, photolysis rates, and boundary concentrations) were specified for the 2016 base year model application and remained unchanged for the projection-year model simulation.

2016 base year emissions are described in detail in U.S. EPA (2023b). The types of sources included in the emission inventory include stationary point sources such as EGUs and non-EGUs; non-point emissions sources including those from oil and gas production and distribution, agriculture, residential wood combustion, fugitive dust, and residential and commercial heating and cooking; mobile source emissions from onroad and nonroad vehicles, aircraft, commercial marine vessels, and locomotives; wild, prescribed, and agricultural fires; and biogenic emissions from vegetation and soils. Future year emissions from all sources other than EGUs were based on the 2026 emissions projections described in U.S. EPA (2023b). The Post-IRA 2022 Reference Case of EPA's Power Sector Platform v6 using Integrated Planning Model (IPM), which includes the Final GNP, was also reflected. The EGU projected inventory represents demand growth, fuel resource availability, generating technology cost and

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[112] This CAMx simulation set the Rscale NH_3 dry deposition parameter to 0 which resulted in more realistic model predictions of $PM_{2.5}$ nitrate concentrations than using a default Rscale parameter of 1.

performance, and other economic factors affecting power sector behavior. It also reflects environmental rules and regulations, consent decrees and settlements, plant closures, and newly built units for the calendar year 2030. In this analysis, the projected EGU emissions include provisions of tax incentives impacting electricity supply in the Inflation Reduction Act of 2022 (IRA), Final GNP, 2021 Revised Cross-State Air Pollution Rule Update (RCU), the 2016 Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources, the Mercury and Air Toxics Rule (MATS) finalized in 2011, and other finalized rules. Documentation and results of the Post-IRA 2022 Reference Case, where the Final GNP was also included for EGUs, are available at (*https://www.epa.gov/power-sector-modeling/final-pm-naaqs*).

Model predictions of ozone and $PM_{2.5}$ concentrations were compared against ambient measurements (U.S. EPA, 2023a, 2024). Ozone and $PM_{2.5}$ model evaluations showed model performance that was adequate for applying these model simulations for the purpose of creating air quality surfaces to estimate ozone and $PM_{2.5}$ benefits.

Figure A-1 Air Quality Modeling Domain

The contributions to ozone and $PM_{2.5}$ component species (e.g., sulfate, nitrate, ammonium, elemental carbon (EC), organic aerosol (OA), and crustal material[113]) from EGU emissions in individual states and from each EGU-fuel type were modeled using the "source

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[113] Crustal material refers to elements that are commonly found in the earth's crust such as Aluminum, Calcium, Iron, Magnesium, Manganese, Potassium, Silicon, Titanium, and the associated oxygen atoms.

apportionment" tool approach. In general, source apportionment modeling quantifies the air quality concentrations formed from individual, user-defined groups of emissions sources or "tags." These source tags are tracked through the transport, dispersion, chemical transformation, and deposition processes within the model to obtain hourly gridded[114] contributions from the emissions in each individual tag to hourly gridded modeled concentrations. For this RIA we used the source apportionment contribution data to provide a means to estimate of the effect of changes in emissions from each group of emissions sources (i.e., each tag) to changes in ozone and $PM_{2.5}$ concentrations. Specifically, we applied outputs from source apportionment modeling for ozone and $PM_{2.5}$ component species using the future year modeled case to obtain the contributions from EGUs emissions in each state and fuel-type to ozone and $PM_{2.5}$ component species concentrations in each 12 km model grid cell nationwide. Ozone contributions were modeled using the Anthropogenic Precursor Culpability Assessment (APCA) tool and $PM_{2.5}$ contributions were modeled using the Particulate Matter Source Apportionment Technology (PSAT) tool (Ramboll Environ, 2021). The ozone source apportionment modeling was performed for the period April through September to provide data for developing spatial fields for the April through September maximum daily eight-hour (MDA8) (i.e., AS-MO3) average ozone concentration exposure metric. The $PM_{2.5}$ source apportionment modeling was performed for a full year to provide data for developing annual average $PM_{2.5}$ spatial fields. Source apportionment simulations were set-up to separately track ozone and $PM_{2.5}$ contributions from coal EGU emissions in each contiguous U.S. state, natural gas EGU emissions in each contiguous U.S. state, and emissions from all other EGUs aggregated across all contiguous U.S. states. In cases where projected EGU emissions for a specific tag and pollutant were either 0 or very small, emissions were combined with nearby states to make multi-state tags. Tables A-1, A-2, and A-3 provide emissions that were tracked for each source apportionment tag.

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[114] Hourly contribution information is provided for each grid cell to provide spatial patterns of the contributions from each tag.

Table A-1 Future-Year Emissions Allocated to Each Modeled Coal EGU State Source Apportionment Tag

State	Ozone Season NO_X (tons)	Annual NO_X (tons)	Annual SO_2 (tons)	Annual $PM_{2.5}$ (tons)
AL	2,537	5,046	1,929	700
AR[4]	NA	304	331	51
AZ	1,005	2,536	4,515	609
CA	222	511	99	27
CO	19	269	287	21
CT	0	0	0	0
DC	0	0	0	0
DE	0	0	0	0
FL	1,110	1,401	7,163	277
GA	1,654	2,534	3,247	159
IA	8,354	18,776	9,656	1,203
ID	0	0	0	0
IL	1,639	3,742	6,773	270
IN	4,886	18,146	26,584	2,252
KS[1]	NA	214	121	NA
KY	3,551	7,333	7,127	560
LA[2,4]	NA	47	NA	NA
MA	0	0	0	0
MD[3]	NA	139	272	31
MD + PA[3]	708	NA	NA	NA
ME	0	0	0	0
MI	1,532	4,071	12,478	380
MN	724	1,549	3,289	94
MO	2,947	23,480	38,989	853
MS[4]	NA	252	507	23
MT	3,771	8,842	4,056	1,252
NC	266	482	634	35
ND	8,583	19,562	25,398	1,923
NE[1]	7,817	17,507	43,858	NA
NE + KS[1]	NA	NA	NA	374
NH	0	0	0	0
NJ	0	0	0	0
NM	1,442	2,757	6,800	1,739
NV	0	1	1	0
NY	0	0	0	0
OH	3,152	10,485	21,721	901
OK[4]	NA	212	152	21
OR	0	0	0	0
PA[3]	NA	1,530	4,932	167
RI	0	0	0	0

SC	807	1,939	3,429	364
SD	418	1,100	1,022	27
TN	259	259	269	32
TX[2,4]	NA	7,031	NA	NA
TX + LA[2]	NA	NA	11,607	1,578
TX-reg[4]	2,698	NA	NA	NA
UT	2,702	4,236	7,625	232
VA	466	1,124	259	445
VT	0	0	0	0
WA	0	0	0	0
WI	866	2,137	838	90
WV	6,824	16,358	17,631	1,753
WY	6,066	13,222	11,754	1,024

[1] KS and NE emissions grouped into multi-state tag for direct $PM_{2.5}$

[2] LA and TX emissions grouped into multi-state tag for SO_2 and direct $PM_{2.5}$

[3] MD and PA emissions grouped into multi-state tag for ozone season NO_X

[4] AR, KS, LA, MS, OK and TX emissions grouped into multi-state tag (“TX-reg”) for ozone season NO_X

Table A-2 Future-Year Emissions Allocated to Each Modeled Natural Gas EGU State Source Apportionment Tag

State	Ozone Season NO_X (tons)	Annual NO_X (tons)	Annual SO_2 (tons)	Annual $PM_{2.5}$ (tons)
AL	2,833	5,132	0	1,979
AR	1,651	2,957	0	632
AZ	1,759	3,146	0	686
CA	1,960	5,773	0	1,964
CO	957	1,825	0	461
CT	461	778	0	160
DC	6	11	0	7
DE	383	502	0	134
FL	7,550	14,372	0	4,996
GA	2,279	4,182	0	1,740
IA	875	1,106	0	327
ID	336	513	0	185
IL	1,624	2,705	0	825
IN	1,180	2,166	0	955
KS	329	621	0	54
KY	980	2,806	0	699
LA	3,771	8,706	0	2,158
MA	482	725	0	244
MD	402	710	0	435
ME	232	273	0	21
MI	6,523	11,372	0	1,508
MN	661	928	0	87
MO	587	875	0	342
MS	1,926	3,860	0	1,140
MT	11	19	0	7
NC	1,803	3,426	0	1,213
ND	25	41	0	3
NE	13	47	0	4
NH	120	136	0	34
NJ	1,024	1,910	0	608
NM	733	1,128	0	131
NV	1,693	2,471	0	648
NY	2,793	5,125	0	1,270
OH	1,838	3,824	0	1,617
OK	1,558	2,448	0	546
OR	5	188	0	87
PA	6,811	12,386	0	3,280
RI	115	153	0	73
SC	1,092	2,090	0	917

SD	93	105	0	11
TN	464	1,107	0	388
TX	7,652	14,715	0	3,567
UT	1,189	1,779	0	514
VA	1,836	3,409	0	1,087
VT	4	8	0	6
WA	485	1,311	0	464
WI	847	1,447	0	369
WV	109	180	0	50
WY	203	206	0	28

Table A-3 Future-Year Emissions Allocated to the Modeled Other EGU Source Apportionment Tag

State	Ozone Season NO_X (tons)	Annual NO_X (tons)	Annual SO_2 (tons)	Annual $PM_{2.5}$ (tons)
US[a]	20,611	48,619	9,631	7,915

[a] Only includes US emissions from the contiguous 48 states

Examples of the magnitude and spatial extent of ozone and $PM_{2.5}$ contributions are provided in through Figure A-5 for EGUs in California, Georgia, Iowa, and Ohio. These figures show how the magnitude and the spatial patterns of contributions of EGU emissions to ozone and $PM_{2.5}$ component species depend on multiple factors including the magnitude and location of emissions as well as the atmospheric conditions that influence the formation and transport of these pollutants. For instance, NO_X emissions are a precursor to both ozone and $PM_{2.5}$ nitrate. However, ozone and nitrate form under very different types of atmospheric conditions, with ozone formation occurring in locations with ample sunlight and ambient VOC concentrations while nitrate formation requires colder and drier conditions and the presence of gas-phase ammonia. California's complex terrain that tends to trap air and allow pollutant build-up combined with warm sunny summer and cooler dry winters and sources of both ammonia and VOCs make its atmosphere conducive to formation of both ozone and nitrate. While the magnitude of EGU NO_X emissions from gas plus coal EGUs is substantially larger in Iowa than in California (Table A-1 and Table A-2) the emissions from California lead to larger maximum contributions to the formation of those pollutants due to the conducive conditions in that state. Georgia and Ohio both had substantial NO_X emissions. While maximum ozone impacts shown for Georgia and Ohio EGUs are similar order of magnitude to maximum ozone impacts from

California EGUs, nitrate impacts are negligible in both Georgia and Ohio due to less conducive atmospheric conditions for nitrate formation in those locations. California EGU SO_2 emissions in the future year source apportionment modeling are several orders of magnitude smaller than SO_2 emissions in Ohio and Georgia (Table A-1) leading to much smaller sulfate contributions from California EGUs than from Ohio and Georgia EGUs. $PM_{2.5}$ organic aerosol EGU contributions in this modeling come from primary $PM_{2.5}$ emissions rather than secondary atmospheric formation. Consequently, the impacts of EGU emissions on this pollutant tend to occur closer to the EGU sources than impacts of secondary pollutants (ozone, nitrate, and sulfate) which have spatial patterns showing a broader regional impact. These patterns demonstrate how the model captures important atmospheric processes which impact pollutant formation and transport from emissions sources. Finally, Figures A-6 and A-7 show EGU ozone and $PM_{2.5}$ contributions from all contiguous U.S. EGUs split out by fuel type. The spatial differences between coal EGU, natural gas EGU, and other EGU contributions reflect the varying location and magnitude of emissions from each type of EGU.

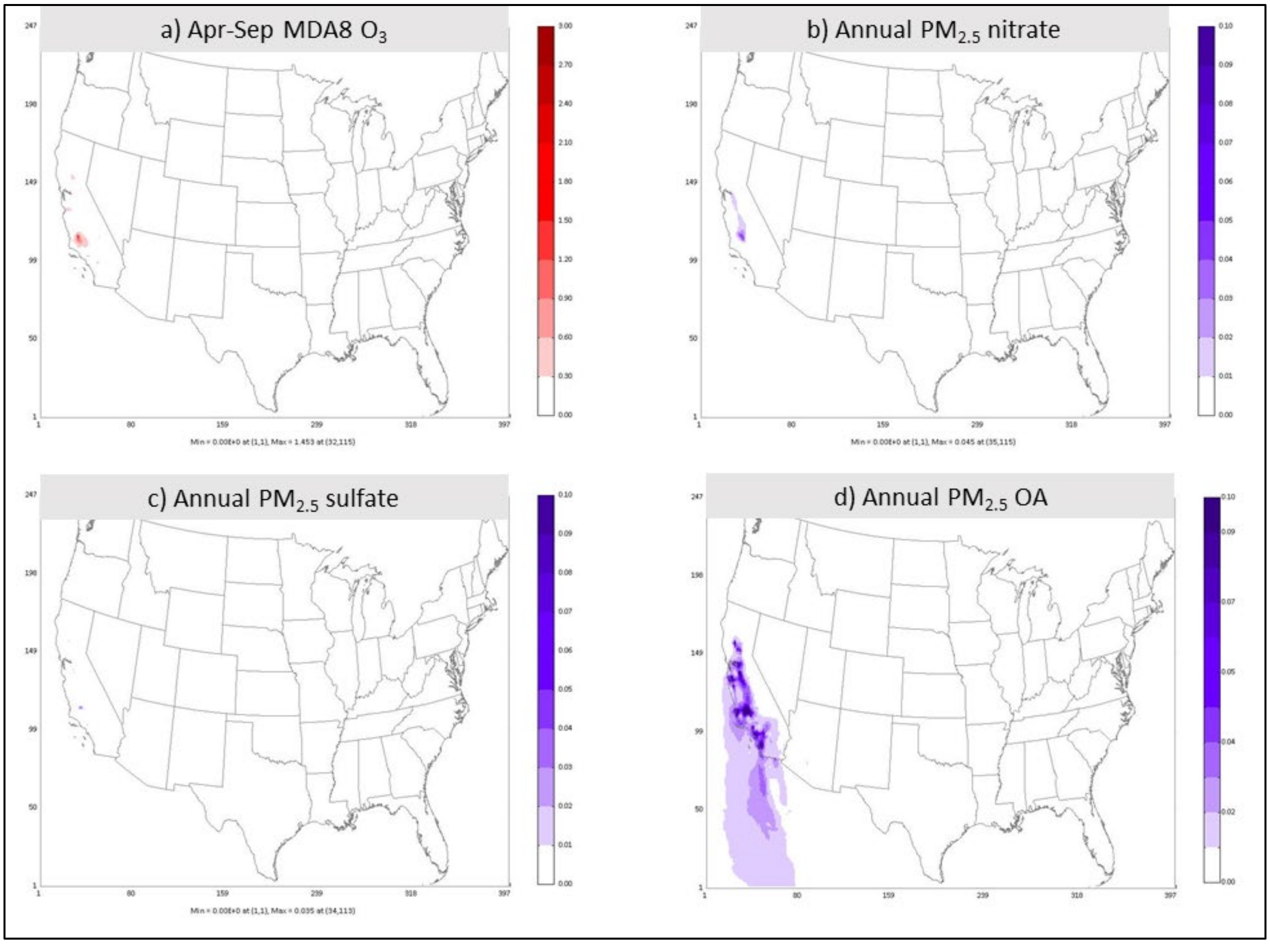

Figure A-2 Maps of California EGU Tag Contributions to a) April-September Seasonal Average MDA8 Ozone (ppb); b) Annual Average PM$_{2.5}$ Nitrate (µg/m3); c) Annual Average PM$_{2.5}$ Sulfate (µg/m3); d) Annual Average PM$_{2.5}$ Organic Aerosol (µg/m3)

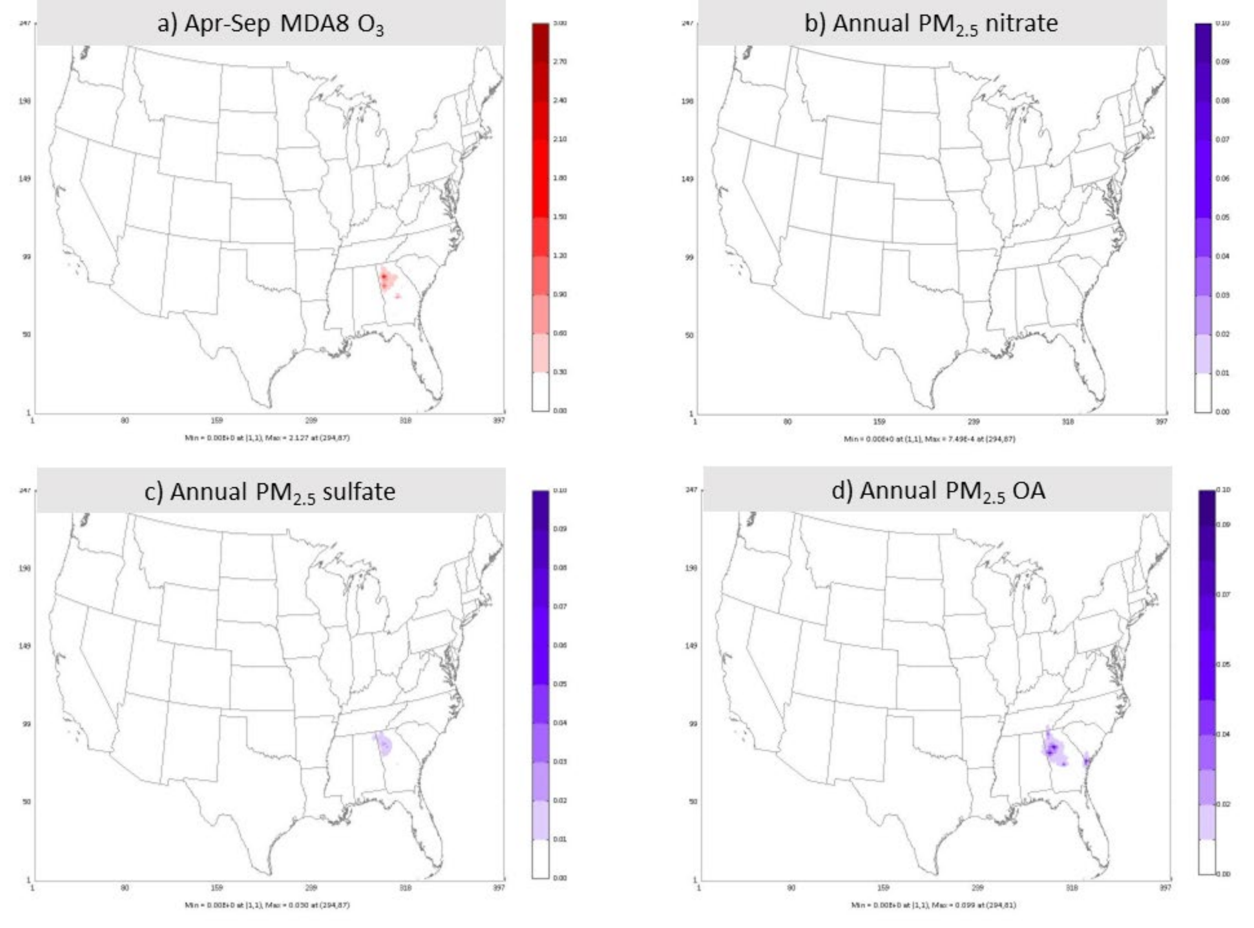

Figure A-3 Maps of Georgia EGU Tag Contributions to a) April-September Seasonal Average MDA8 Ozone (ppb); b) Annual Average $PM_{2.5}$ Nitrate µg/m^3); c) Annual Average $PM_{2.5}$, Sulfate (µg/m^3); d) Annual Average $PM_{2.5}$ Organic Aerosol (µg/m^3)

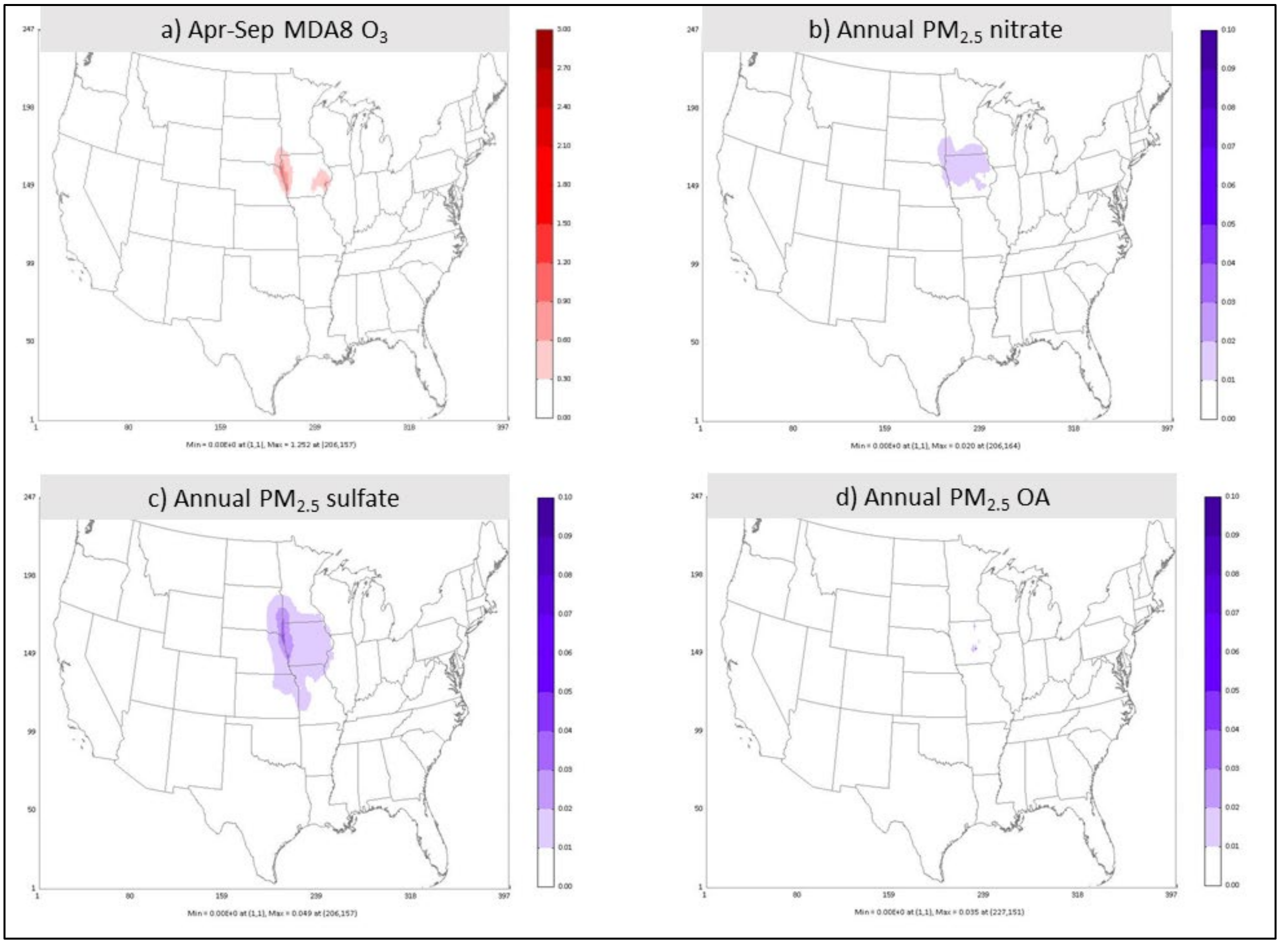

Figure A-4 Maps of Iowa EGU Tag contributions to a) April-September Seasonal Average MDA8 Ozone (ppb); b) Annual Average $PM_{2.5}$ Nitrate ($\mu g/m^3$); c) Annual Average $PM_{2.5}$ Sulfate ($\mu g/m^3$); d) Annual Average $PM_{2.5}$ Organic Aerosol ($\mu g/m^3$)

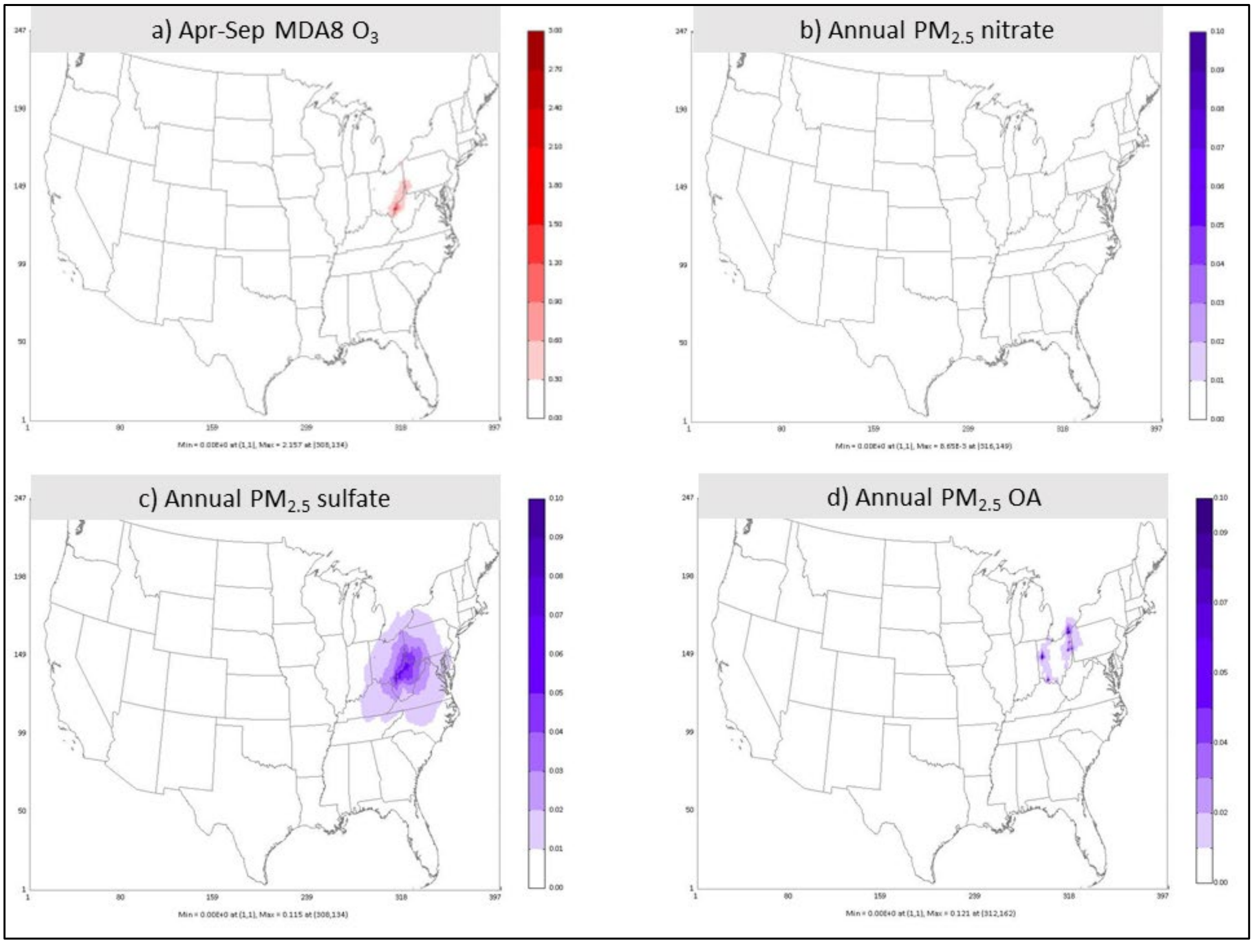

Figure A-5 Maps of Ohio EGU Tag Contributions to a) April-September Seasonal Average MDA8 Ozone (ppb); b) Annual Average $PM_{2.5}$ Nitrate ($\mu g/m^3$); c) Annual Average $PM_{2.5}$ Sulfate ($\mu g/m^3$); d) Annual Average $PM_{2.5}$ Organic Aerosol ($\mu g/m^3$)

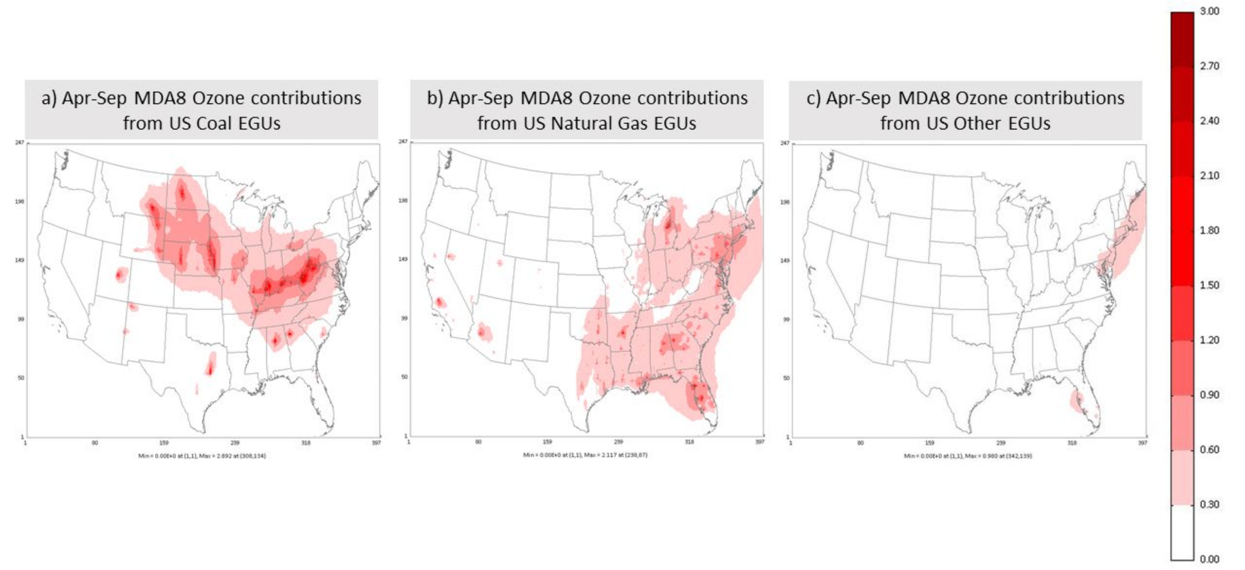

Figure A-6 Maps of national EGU Tag Contributions to April-September Seasonal Average MDA8 Ozone (ppb) by fuel for a) coal EGUs; b) natural gas EGUs; c) all other EGUs

Figure A-7 Maps of national EGU Tag Contributions Annual Average PM$_{2.5}$ (µg/m^3) by fuel for a) coal EGUs; b) natural gas EGUs; c) all other EGUs

A.3 Applying Modeling Outputs to Create Spatial Fields

In this section we describe the method for creating spatial fields of AS-MO3 and annual average PM$_{2.5}$ based on the 2016 and future year modeling. The foundational data include (1) ozone and speciated PM$_{2.5}$ concentrations in each model grid cell from the 2016 and the future year modeling, (2) ozone and speciated $PM_{2.5}$ contributions in the future year of EGUs emissions from each state in each model grid cell,[115] (3) future year emissions from EGUs that were input to the contribution modeling (Table A-1, Table A-2, Table A-3), and (4) the EGU emissions from IPM for baseline and the final rule scenarios in each analytic year. The method to create spatial fields applies scaling factors to gridded source apportionment contributions based on emissions changes between future year projections and the baseline and the final rule options to the modeled contributions. This method is described in detail below.

Spatial fields of ozone and $PM_{2.5}$for the future year were created based on "fusing" modeled data with measured concentrations at air quality monitoring locations. To create the spatial fields for each future emissions scenario, these fused future year model fields are used in combination with the EGU source apportionment modeling and the EGU emissions for each scenario and analytic year. Contributions from each state and fuel EGU contribution "tag" were scaled based on the ratio of emissions in the year/scenario being evaluated to the emissions in the modeled scenario. Contributions from tags representing sources other than EGUs are held constant at 2026 levels for each of the scenarios and year. For each scenario and year analyzed, the scaled contributions from all sources were summed together to create a gridded surface of total modeled ozone and $PM_{2.5}$. The process is described in a step-by-step manner below starting with the methodology for creating AS-MO3 spatial fields followed by a description of the steps for creating annual $PM_{2.5}$ spatial fields.

Ozone:

1. Create fused spatial fields of future year AS-MO3 incorporating information from the air quality modeling and from ambient measured monitoring data. The enhanced Voronoi Neighbor Average (eVNA) technique (Ding et al., 2016; Gold et al., 1997; U.S. EPA, 2007) was applied to ozone model predictions in conjunction with measured data to create modeled/measured fused surfaces that leverage measured concentrations at air quality monitor locations and model predictions at locations with no monitoring data.
    1.1. The AS-MO3 eVNA spatial fields are created for the 2016 base year with EPA's software package, Software for the Modeled Attainment Test – Community Edition

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[115] Contributions from EGUs were modeled using projected emissions for the modeled scenario. The resulting contributions were used to construct spatial fields in 2028, 2030, and 2035.

(SMAT-CE)[116] (U.S. EPA, 2022b) using three years of monitoring data (2015-2017) and the 2016 modeled data.

1.2. The model-predicted spatial fields (i.e., not the eVNA fields) of AS-MO3 in 2016 were paired with the corresponding model-predicted spatial fields in the future year to calculate the ratio of AS-MO3 between 2016 and the future year in each model grid cell.

1.3. To create a gridded future year eVNA surfaces, the spatial fields of 2016/future year ratios created in step 1.2 were multiplied by the corresponding eVNA spatial fields for 2016 created in step 1.1 to produce an eVNA AS-MO3 spatial field for future year using (Eq-1).

$$\mathrm{eVNA}_{\mathrm{g,future}} = \left(\mathrm{eVNA}_{\mathrm{g,2016}}\right) \times \frac{\mathrm{Model}_{\mathrm{g,future}}}{\mathrm{Model}_{\mathrm{g,2016}}} \qquad \text{Eq-1}$$

- $\mathrm{eVNA}_{\mathrm{g,future}}$ is the eVNA concentration of AS-MO3 or $PM_{2.5}$ component species in grid-cell, g, in the future year
- $\mathrm{eVNA}_{\mathrm{g,2016}}$ is the eVNA concentration of AS-MO3 or $PM_{2.5}$ component species in grid-cell, g, in 2016
- $\mathrm{Model}_{\mathrm{g,future}}$ is the CAMx modeled concentration of AS-MO3 or $PM_{2.5}$ component species in grid-cell, g, in the future year
- $\mathrm{Model}_{\mathrm{g,2016}}$ is the CAMx modeled concentration of AS-MO3 or $PM_{2.5}$ component in grid-cell, g, in 2016

2. Create gridded spatial fields of total EGU AS-MO3 contributions for each combination of scenario and analytic year evaluated.

2.1. Use the EGU ozone season NO_X emissions for the 2028 baseline and the corresponding future year modeled EGU ozone season emissions (Table A-1, Table A-2, and Table A-3) to calculate the ratio of 2028 baseline emissions to future year modeled emissions for

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[116] SMAT-CE available for download at *https://www.epa.gov/scram/photochemical-modeling-tools*.

each EGU tag (i.e., an ozone scaling factor calculated for each state-fuel tag).[117] These scaling factors are provided in Table A-, A-5 and A-11.

2.2. Calculate adjusted gridded AS-MO3 EGU contributions that reflect differences in state-fuel EGU NO_X emissions between the modeled future year and the 2028 baseline by multiplying the ozone season NO_X scaling factors by the corresponding gridded AS-MO3 ozone contributions[118] from each state-fuel EGU tag.

2.3. Add together the adjusted AS-MO3 contributions for each state-fuel EGU tag to produce spatial fields of adjusted EGU totals for the 2028 baseline.[119]

2.4. Repeat steps 2.1 through 2.3 for the 2028 final rule scenario and for the baseline and final rule scenarios for each additional analytic year. All scaling factors for the baseline scenario and the regulatory control alternatives are provided in Tables A-4, A-5, and A-11.

3. Create a gridded spatial field of AS-MO3 associated with IPM emissions for the 2028 baseline by combining the EGU AS-MO3 contributions from step 2.3 with the corresponding contributions to AS-MO3 from all other sources. Repeat for each of the EGU contributions created in step 2.4 to create separate gridded spatial fields for the 2028 final rule scenario and the baseline and final rule scenario for the two other analytic years.

Steps 2 and 3 in combination can be represented by equation 2:

$$\begin{aligned}\text{AS-MO3}_{g,i,y} = {} & \text{eVNA}_{g,\text{future}} \\ & \times \left(\frac{C_{g,BC}}{C_{g,Tot}} + \frac{C_{g,int}}{C_{g,Tot}} + \frac{C_{g,bio}}{C_{g,Tot}} + \frac{C_{g,fires}}{C_{g,Tot}} + \frac{C_{g,USanthro}}{C_{g,Tot}} \right. \\ & \left. + \sum_{t=1}^{T} \frac{C_{EGUVOC,g,t}}{C_{g,Tot}} + \sum_{t=1}^{T} \frac{C_{EGUNOx,g,t}\, S_{NOx,t,i,y}}{C_{g,Tot}} \right)\end{aligned} \qquad \text{Eq-2}$$

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[117] State-level tags were tracked for separately for coal EGUs and for natural gas EGUs. All other EGU emissions were tracked using a single national tag. In addition, preliminary testing of this methodology showed unstable results when very small magnitudes of emissions were tagged especially when being scaled by large factors. To mitigate this issue, in cases where state-fuel EGU tags were associated with no or very small emissions, tags were combined into multi-state regions.

[118] The source apportionment modeling provided separate ozone contributions for ozone formed in VOC-limited chemical regimes (O3V) and ozone formed in NO_X-limited chemical regimes (O3N). The emissions scaling factors are multiplied by the corresponding O3N gridded contributions to MDA8 concentrations. Since there are no predicted changes in VOC emissions in the control scenarios, the O3V contributions remain unchanged.

[119] The contributions from the unaltered O3V tags are added to the summed adjusted O3N EGU tags.

- $\text{AS-MO3}_{g,i,y}$ is the estimated fused model-obs AS-MO3 for grid-cell, “g,” scenario, “i,”[120] and year, “y;”[121]
- $\text{eVNA}_{g,future}$ is the future year eVNA future year AS-MO3 concentration for grid-cell “g” calculated using Eq-1;
- $C_{g,Tot}$ is the total modeled AS-MO3 for grid-cell “g” from all sources in the future year source apportionment modeling;
- $C_{g,BC}$ is the future year AS-MO3 modeled contribution from the modeled boundary inflow;
- $C_{g,int}$ is the future year AS-MO3 modeled contribution from international emissions within the modeling domain;
- $C_{g,bio}$ is the future year AS-MO3 modeled contribute/on from biogenic emissions;
- $C_{g,fires}$ is the future year AS-MO3 modeled contribution from fires;
- $C_{g,USanthro}$ is the total future year AS-MO3 modeled contribution from U.S. anthropogenic sources other than EGUs;
- $C_{EGUVOC,g,t}$ is the future year AS-MO3 modeled contribution from EGU emissions of VOCs from tag, “t”;
- $C_{EGUNOx,g,t}$ is the future year AS-MO3 modeled contribution from EGU emissions of NO_X from tag, “t”; and
- $S_{NOx,t,i,y}$ is the EGU NO_X scaling factor for tag, “t,” scenario, “i,” and year, “y.”

$PM_{2.5}$

4. Create fused spatial fields of future year annual $PM_{2.5}$ component species incorporating information from the air quality modeling and from ambient measured monitoring data. The eVNA technique was applied to $PM_{2.5}$ component species model predictions in conjunction with measured data to create modeled/measured fused surfaces that leverage measured concentrations at air quality monitor locations and model predictions at locations with no monitoring data.

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[120] Scenario “i" can represent either the baseline or the final rule scenario.
[121] Year “y” can represent 2028, 2030, or 2035.

4.1. The quarterly average $PM_{2.5}$ component species eVNA spatial fields are created for the 2016 base year with EPA's SMAT-CE software package using three years of monitoring data (2015-2017) and the 2016 modeled data.

4.2. The model-predicted spatial fields (i.e., not the eVNA fields) of quarterly average $PM_{2.5}$ component species in 2016 were paired with the corresponding future year model-predicted spatial fields to calculate the ratio of $PM_{2.5}$ component species between 2016 and the future year in each model grid cell.

4.3. To create a gridded future year eVNA surfaces, the spatial fields of 2016/future year ratios created in step 4.2 were multiplied by the corresponding eVNA spatial fields for 2016 created in step 4.1 to produce an eVNA annual average $PM_{2.5}$ component species spatial field for the future year using Eq-1.

5. Create gridded spatial fields of total EGU speciated $PM_{2.5}$ contributions for each combination of scenario and analytic year evaluated.

5.1. Use the EGU annual total NO_X, SO_2, and $PM_{2.5}$ emissions for the 2028 baseline scenario and the corresponding future year modeled EGU NO_X, SO_2, and $PM_{2.5}$ emissions from Table A-1, Table A-2 and Table A-3 to calculate the ratio of 2028 baseline emissions to future year modeled emissions for each EGU state-fuel contribution tag (i.e., annual nitrate, sulfate and directly emitted $PM_{2.5}$ scaling factors calculated for each state-fuel tag).[122] These scaling factors are provided in Table A-6 through Table A-11.

5.2. Calculate adjusted gridded annual $PM_{2.5}$ component species EGU contributions that reflect differences in state-EGU NO_X, SO_2, and primary $PM_{2.5}$ emissions between the modeled future year and the 2028 baseline by multiplying the annual nitrate, sulfate and directly emitted $PM_{2.5}$ scaling factors by the corresponding annual gridded $PM_{2.5}$ component species contributions from each state-fuel EGU tag.[123]

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[122] State-level tags were tracked for separately for coal EGUs and for natural gas EGUs. All other EGU emissions were tracked using a single national tag. In addition, preliminary testing of this methodology showed unstable results when very small magnitudes of emissions were tagged especially when being scaled by large factors. To mitigate this issue, in cases where state-fuel EGU tags were associated with no or very small emissions, tags were combined into multi-state regions.

[123] Scaling factors for components that are formed through chemical reactions in the atmosphere were created as follows: scaling factors for sulfate were based on relative changes in annual SO_2 emissions; scaling factors for

5.3. Add together the adjusted $PM_{2.5}$ contributions of for each EGU state tag to produce spatial fields of adjusted EGU totals for each $PM_{2.5}$ component species.

5.4. Repeat steps 5.1 through 5.3 for the final rule scenario in 2028 and for the baseline and the final rule scenario for each additional analytic year. The scaling factors for all $PM_{2.5}$ component species for the baseline and final rule scenarios are provided in Table A-6 through Table A-11

6. Create gridded spatial fields of each $PM_{2.5}$ component species for the 2028 baseline by combining the EGU annual $PM_{2.5}$ component species contributions from step 5.3 with the corresponding contributions to annual $PM_{2.5}$ component species from all other sources. Repeat for each of the EGU contributions created in step 5.4 to create separate gridded spatial fields for the baseline and final rule scenarios for all other analytic years.
7. Create gridded spatial fields of total $PM_{2.5}$ mass by combining the component species surfaces for sulfate, nitrate, organic aerosol, elemental carbon, and crustal material with ammonium, and particle-bound water. Ammonium and particle-bound water concentrations are calculated for each scenario based on nitrate and sulfate concentrations along with the ammonium degree of neutralization in the base year modeling (2016) in accordance with equations from the SMAT-CE modeling software (U.S. EPA, 2022bfi).

Steps 5 and 6 result in Eq-3 for $PM_{2.5}$ component species: sulfate, nitrate, organic aerosol, elemental carbon, and crustal material.

$$\begin{aligned}\mathrm{PM}_{\mathrm{s,g,i,y}} = \mathrm{eVNA}_{\mathrm{s,g,future}} \\ \times \left(\frac{\mathrm{C}_{\mathrm{s,g,BC}}}{\mathrm{C}_{\mathrm{s,g,Tot}}} + \frac{\mathrm{C}_{\mathrm{s,g,int}}}{\mathrm{C}_{\mathrm{s,g,Tot}}} + \frac{\mathrm{C}_{\mathrm{s,g,bio}}}{\mathrm{C}_{\mathrm{s,g,Tot}}} + \frac{\mathrm{C}_{\mathrm{s,g,fires}}}{\mathrm{C}_{\mathrm{s,g,Tot}}} + \frac{\mathrm{C}_{\mathrm{s,g,USanthro}}}{\mathrm{C}_{\mathrm{s,g,Tot}}} \right. \\ \left. + \sum_{\mathrm{t=1}}^{\mathrm{T}} \frac{\mathrm{C}_{\mathrm{EGUs,g,t}}\, \mathrm{S}_{\mathrm{s,t,i,y}}}{\mathrm{C}_{\mathrm{s,g,Tot}}}\right)\end{aligned} \qquad \text{Eq-3}$$

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nitrate were based on relative changes in annual NO_X emissions. Scaling factors for $PM_{2.5}$ components that are emitted directly from the source (OA, EC, crustal) were based on the relative changes in annual primary $PM_{2.5}$ emissions between the future year modeled emissions and the baseline or the final rule scenario in each year.

- $PM_{s,g,i,y}$ is the estimated fused model-obs PM component species "s" for grid-cell, "g," scenario, "i,"[124] and year, "y;"[125]
- $eVNA_{s,g,future}$ is the future year eVNA PM concentration for component species "s" in grid-cell "g" calculated using Eq-1;
- $C_{s,g,Tot}$ is the total modeled PM component species "s" for grid-cell "g" from all sources in the 2026 source apportionment modeling;
- $C_{s,g,BC}$ is the future year PM component species "s" modeled contribution from the modeled boundary inflow;
- $C_{s,g,int}$ is the future year PM component species "s" modeled contribution from international emissions within the modeling domain;
- $C_{s,g,bio}$ is the future year PM component species "s" modeled contribution from biogenic emissions;
- $C_{s,g,fires}$ is the future year PM component species "s" modeled contribution from fires;
- $C_{s,g,USanthro}$ is the total future year PM component species "s" modeled contribution from U.S. anthropogenic sources other than EGUs;
- $C_{EGUs,g,t}$ is the future year PM component species "s" modeled contribution from EGU emissions of NO_X, SO_2, or primary $PM_{2.5}$ from tag, "t"; and
- $S_{s,t,i,y}$ is the EGU scaling factor for component species "s," tag "t," scenario "i," and year "y." Scaling factors for nitrate are based on annual NO_x emissions, scaling factors for sulfate are based on annual SO_2 emissions, scaling factors for primary $PM_{2.5}$ components are based on primary $PM_{2.5}$ emissions.

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[124] Scenario "i" can represent either baseline or the final rule scenario.
[125] Year "y" can represent 2028, 2030, or 2035.

A.4 Scaling Factors Applied to Source Apportionment Tags

Table A-4 Ozone Seasonal NO_X Scaling Factors for Coal EGU Tags in the Baseline and the Final Rule

	Baseline			Final Rule		
State Tag	**2028**	**2030**	**2035**	**2028**	**2030**	**2035**
AL	1.20	1.40	1.47	1.20	1.40	1.47
AZ	0.01	1.43	1.13	0.01	1.43	1.17
CA	0.00	0.00	0.00	0.00	0.00	0.00
CO	139.01	1.28	1.98	139.01	1.28	1.98
CT	0.00	0.00	0.00	0.00	0.00	0.00
DC	0.00	0.00	0.00	0.00	0.00	0.00
DE	0.00	0.00	0.00	0.00	0.00	0.00
FL	0.47	1.24	0.10	0.47	1.24	0.10
GA	0.00	0.18	0.00	0.00	0.18	0.00
IA	1.17	1.18	0.77	1.17	1.18	0.77
ID	0.00	0.00	0.00	0.00	0.00	0.00
IL	0.97	0.96	0.81	0.97	0.96	0.81
IN	1.35	0.76	0.19	1.35	0.76	0.19
KY	0.79	0.95	0.97	0.79	0.95	0.98
MA	0.00	0.00	0.00	0.00	0.00	0.00
MDPA[a]	3.14	3.17	2.58	3.14	3.17	2.58
ME	0.00	0.00	0.00	0.00	0.00	0.00
MI	0.75	0.00	0.00	0.75	0.00	0.00
MN	2.41	2.25	0.00	2.41	2.25	0.00
MO	2.72	1.57	0.67	2.71	1.57	0.67
MT	1.07	1.12	1.11	1.07	1.12	1.09
NC	9.89	6.41	2.86	9.92	6.43	2.86
ND	1.09	1.08	0.25	1.06	1.08	0.25
NE	1.16	1.18	0.73	1.16	1.18	0.74
NH	0.00	0.00	0.00	0.00	0.00	0.00
NJ	0.00	0.00	0.00	0.00	0.00	0.00
NM	0.98	0.98	0.01	0.98	0.98	0.01
NV	0.00	0.00	0.00	0.00	0.00	0.00
NY	0.00	0.00	0.00	0.00	0.00	0.00
OH	0.58	1.07	0.00	0.58	1.07	0.00
OR	0.00	0.00	0.00	0.00	0.00	0.00
RI	0.00	0.00	0.00	0.00	0.00	0.00
SC	0.81	2.22	3.18	0.81	2.22	3.18
SD	0.87	1.33	0.00	0.87	1.33	0.00
TN	3.89	0.01	0.00	3.89	0.01	0.00
TX-reg[b]	4.69	4.26	1.64	4.70	4.26	1.64
UT	1.00	0.06	0.06	1.00	0.06	0.06

State Tag	Baseline 2028	Baseline 2030	Baseline 2035	Final Rule 2028	Final Rule 2030	Final Rule 2035
VA	0.65	0.45	0.00	0.65	0.45	0.00
VT	0.00	0.00	0.00	0.00	0.00	0.00
WA	0.00	0.00	0.00	0.00	0.00	0.00
WI	1.66	2.16	0.36	1.69	2.16	0.36
WV	0.92	1.16	0.92	0.92	1.16	0.91
WY	1.26	1.12	1.12	1.26	1.12	1.12

Note: Emissions from Maryland, Arkansas, Kansas, Louisiana, Oklahoma, and Mississippi are less than 10 tpy in the original source apportionment modeling. Air quality impacts and emissions from those states were combined with nearby states.

[a] MDPA: Maryland and Pennsylvania

[b] TX-reg: Arkansas, Kansas, Louisiana, Oklahoma, Mississippi, Texas

Table A-5 Ozone Seasonal NO_X Scaling Factors for Gas EGU Tags in the Baseline and the Final Rule

	Baseline			Final Rule		
State Tag	2028	2030	2035	2028	2030	2035
AL	0.53	0.61	0.49	0.53	0.61	0.49
AR	0.65	0.68	0.43	0.63	0.68	0.43
AZ	0.69	0.68	0.67	0.69	0.68	0.67
CA	0.92	0.94	0.85	0.92	0.94	0.85
CO	3.26	0.63	0.50	3.26	0.63	0.50
CT	1.04	0.98	0.89	1.04	0.98	0.89
DC	0.86	0.59	0.33	0.86	0.59	0.33
DE	0.79	0.80	0.38	0.79	0.80	0.38
FL	1.08	1.03	1.04	1.08	1.03	1.04
GA	0.58	0.54	0.52	0.58	0.54	0.52
IA	0.53	0.42	0.16	0.53	0.42	0.16
ID	0.60	0.90	0.90	0.59	0.91	0.89
IL	0.69	0.61	0.42	0.68	0.61	0.42
IN	0.75	0.63	0.38	0.75	0.63	0.38
KS	1.38	1.32	0.25	1.38	1.32	0.24
KY	0.87	0.81	0.69	0.86	0.81	0.69
LA	1.04	1.00	0.72	1.04	1.00	0.72
MA	0.60	0.67	0.66	0.60	0.67	0.66
MD	1.51	1.33	1.12	1.51	1.33	1.12
ME	1.16	1.15	0.59	1.16	1.15	0.59
MI	0.68	0.70	0.55	0.68	0.70	0.55
MN	0.92	0.84	0.34	0.92	0.84	0.34
MO	0.59	0.59	0.20	0.58	0.59	0.20
MS	0.64	0.62	0.50	0.64	0.62	0.50
MT	0.95	1.10	0.08	0.95	1.10	0.09
NC	0.77	0.59	0.68	0.77	0.59	0.68
ND	0.85	1.85	0.34	0.82	1.85	0.34
NE	5.91	5.92	0.28	5.91	5.92	0.29
NH	0.67	0.51	0.41	0.67	0.51	0.41
NJ	0.81	0.85	0.61	0.81	0.85	0.62
NM	1.00	0.84	0.77	1.00	0.84	0.77
NV	0.33	0.25	0.19	0.33	0.25	0.19
NY	1.03	0.99	0.65	1.03	0.99	0.64
OH	1.02	0.97	0.84	1.03	0.97	0.84
OK	1.69	1.57	0.48	1.69	1.57	0.47
OR	63.29	0.00	0.00	63.55	0.00	0.00
PA	0.79	0.69	0.34	0.79	0.69	0.34
RI	0.69	0.75	0.71	0.69	0.75	0.71

State Tag	Baseline 2028	Baseline 2030	Baseline 2035	Final Rule 2028	Final Rule 2030	Final Rule 2035
SC	0.93	0.96	0.59	0.93	0.96	0.59
SD	0.59	0.59	0.17	0.59	0.59	0.17
TN	1.12	1.09	1.07	1.12	1.09	1.07
TX	0.99	0.89	0.47	0.99	0.89	0.47
UT	0.50	0.43	0.34	0.50	0.43	0.34
VA	0.89	0.85	0.54	0.88	0.85	0.54
VT	0.00	0.37	3.53	0.00	0.37	3.53
WA	0.08	0.23	0.79	0.08	0.23	0.79
WI	0.74	0.70	0.58	0.74	0.70	0.57
WV	1.19	1.12	0.33	1.19	1.12	0.33
WY	0.01	0.04	0.06	0.01	0.04	0.07

Table A-6 Nitrate Scaling Factors for Coal EGU Tags in the Baseline and the Final Rule

	Baseline			Final Rule		
State Tag	2028	2030	2035	2028	2030	2035
AL	1.33	1.45	1.65	1.33	1.45	1.65
AR	39.93	8.30	3.83	39.92	8.32	3.83
AZ	0.47	0.97	0.59	0.47	0.97	0.61
CA	0.24	0.36	0.16	0.24	0.36	0.16
CO	25.56	0.97	0.37	25.57	0.97	0.37
CT	0.00	0.00	0.00	0.00	0.00	0.00
DC	0.00	0.00	0.00	0.00	0.00	0.00
DE	0.00	0.00	0.00	0.00	0.00	0.00
FL	0.89	1.20	0.26	0.89	1.20	0.26
GA	0.23	0.12	0.00	0.23	0.12	0.00
IA	1.20	1.16	0.68	1.20	1.16	0.68
ID	0.00	0.00	0.00	0.00	0.00	0.00
IL	0.98	0.92	0.62	0.98	0.92	0.62
IN	1.29	0.64	0.11	1.28	0.65	0.11
KS	45.15	46.03	3.08	45.15	46.03	3.08
KY	1.38	1.12	1.15	1.38	1.12	1.16
LA	24.63	16.33	25.37	24.63	16.33	25.37
MA	0.00	0.00	0.00	0.00	0.00	0.00
MD	3.54	3.54	3.54	3.54	3.54	3.54
ME	0.00	0.00	0.00	0.00	0.00	0.00
MI	0.74	0.00	0.00	0.74	0.00	0.00
MN	2.97	2.31	0.00	2.97	2.31	0.00
MO	1.41	1.06	0.43	1.40	1.06	0.43
MS	4.02	3.60	1.06	4.01	3.60	1.06
MT	1.07	1.09	1.08	1.07	1.09	1.07
NC	19.19	11.95	3.66	19.22	11.95	3.67
ND	1.03	1.03	0.25	1.02	1.03	0.25
NE	1.14	1.13	0.61	1.14	1.13	0.62
NH	0.00	0.00	0.00	0.00	0.00	0.00
NJ	0.00	0.00	0.00	0.00	0.00	0.00
NM	0.99	0.99	0.01	0.99	0.99	0.01
NV	0.00	0.00	0.00	0.00	0.00	0.00
NY	0.00	0.00	0.00	0.00	0.00	0.00
OH	0.90	0.94	0.19	0.90	0.94	0.19
OK	12.10	5.08	3.11	12.08	5.07	3.11
OR	0.00	0.00	0.00	0.00	0.00	0.00
PA	3.05	2.94	2.61	3.05	2.94	2.61
RI	0.00	0.00	0.00	0.00	0.00	0.00

State Tag	Baseline 2028	Baseline 2030	Baseline 2035	Final Rule 2028	Final Rule 2030	Final Rule 2035
SC	1.15	1.92	2.98	1.14	1.92	2.98
SD	0.93	1.11	0.00	0.93	1.11	0.00
TN	7.49	1.00	0.00	7.49	1.00	0.00
TX	1.02	1.13	0.87	1.02	1.13	0.87
UT	3.50	0.09	0.09	3.50	0.09	0.09
VA	0.67	0.41	0.12	0.67	0.41	0.12
VT	0.00	0.00	0.00	0.00	0.00	0.00
WA	0.00	0.00	0.00	0.00	0.00	0.00
WI	1.84	2.07	0.38	1.85	2.07	0.38
WV	1.25	1.30	0.97	1.25	1.30	0.97
WY	1.32	1.15	1.14	1.32	1.15	1.14

Table A-7 Nitrate Scaling Factors for Gas EGU Tags in the Baseline and the Final Rule

	Baseline			Final Rule		
State Tag	2028	2030	2035	2028	2030	2035
AL	0.59	0.60	0.45	0.59	0.60	0.45
AR	0.56	0.68	0.38	0.55	0.68	0.38
AZ	0.73	0.85	0.83	0.73	0.85	0.83
CA	0.76	0.88	0.97	0.76	0.88	0.97
CO	2.02	0.71	0.72	2.02	0.71	0.72
CT	0.92	0.81	0.66	0.92	0.81	0.66
DC	0.63	0.47	0.26	0.63	0.47	0.26
DE	0.79	0.76	0.33	0.79	0.76	0.33
FL	1.11	1.06	1.01	1.10	1.06	1.01
GA	0.68	0.63	0.54	0.68	0.63	0.54
IA	0.49	0.42	0.13	0.49	0.42	0.13
ID	1.02	1.36	1.39	1.01	1.36	1.38
IL	0.54	0.54	0.29	0.53	0.54	0.29
IN	0.67	0.59	0.34	0.66	0.59	0.34
KS	0.96	0.87	0.20	0.96	0.88	0.20
KY	0.81	0.76	0.46	0.81	0.76	0.46
LA	0.96	0.94	0.61	0.96	0.94	0.61
MA	0.64	0.66	0.54	0.64	0.66	0.54
MD	1.47	1.35	1.05	1.47	1.35	1.05
ME	1.64	1.34	0.63	1.64	1.34	0.63
MI	0.65	0.71	0.43	0.65	0.71	0.43
MN	1.02	0.95	0.36	1.02	0.95	0.36
MO	0.52	0.52	0.19	0.52	0.52	0.19
MS	0.61	0.56	0.36	0.61	0.56	0.36
MT	0.66	0.80	0.05	0.66	0.80	0.06
NC	0.89	0.67	0.72	0.89	0.67	0.72
ND	0.66	1.32	0.26	0.65	1.31	0.26
NE	2.05	1.80	0.13	2.05	1.80	0.13
NH	0.78	0.59	0.44	0.78	0.59	0.44
NJ	0.82	0.83	0.51	0.82	0.83	0.52
NM	0.74	0.66	0.64	0.74	0.66	0.64
NV	0.50	0.39	0.44	0.50	0.39	0.44
NY	0.91	0.89	0.55	0.91	0.89	0.55
OH	1.00	0.98	0.87	1.00	0.98	0.87
OK	1.43	1.20	0.34	1.44	1.20	0.34
OR	5.58	0.96	0.50	5.59	0.96	0.49
PA	0.69	0.61	0.35	0.69	0.61	0.35
RI	0.76	0.76	0.64	0.77	0.76	0.64
SC	0.94	0.96	0.67	0.94	0.96	0.67
SD	0.55	0.55	0.16	0.55	0.55	0.16

	Baseline			Final Rule		
State Tag	**2028**	**2030**	**2035**	**2028**	**2030**	**2035**
TN	1.02	0.97	0.79	1.02	0.97	0.80
TX	0.97	0.88	0.42	0.97	0.89	0.42
UT	0.52	0.62	0.56	0.52	0.62	0.56
VA	0.84	0.80	0.43	0.84	0.80	0.43
VT	0.10	0.16	1.53	0.10	0.16	1.53
WA	0.43	0.36	0.72	0.43	0.36	0.72
WI	0.66	0.67	0.45	0.66	0.67	0.44
WV	1.02	0.89	0.22	1.02	0.89	0.22
WY	0.01	0.04	0.06	0.01	0.04	0.06

Table A-8 Sulfate Scaling Factors for Coal EGU Tags in the Baseline and the Final Rule

	Baseline			Final Rule		
State Tag	2028	2030	2035	2028	2030	2035
AL	4.96	5.39	7.07	4.96	5.39	7.07
AR	118.10	7.02	4.45	118.07	7.04	4.45
AZ	0.48	1.42	1.16	0.48	1.42	1.16
CA	0.33	0.50	0.26	0.33	0.50	0.26
CO	14.31	0.98	0.20	14.31	0.98	0.20
CT	0.00	0.00	0.00	0.00	0.00	0.00
DC	0.00	0.00	0.00	0.00	0.00	0.00
DE	0.00	0.00	0.00	0.00	0.00	0.00
FL	0.98	1.16	0.50	0.98	1.16	0.50
GA	0.04	0.09	0.00	0.04	0.09	0.00
IA	1.31	1.25	0.78	1.31	1.25	0.78
ID	0.00	0.00	0.00	0.00	0.00	0.00
IL	1.01	0.73	0.48	1.01	0.73	0.48
IN	0.89	0.56	0.12	0.89	0.56	0.12
KS	52.35	51.92	11.39	52.35	51.92	11.39
KY	2.68	2.12	1.88	2.68	2.11	1.88
MA	0.00	0.00	0.00	0.00	0.00	0.00
MD	3.54	3.54	3.54	3.54	3.54	3.54
ME	0.00	0.00	0.00	0.00	0.00	0.00
MI	0.85	0.00	0.00	0.85	0.00	0.00
MN	1.68	1.47	0.00	1.68	1.47	0.00
MO	2.20	1.08	0.71	2.20	1.08	0.71
MS	4.02	3.60	1.06	4.01	3.60	1.06
MT	1.85	2.06	1.92	1.85	2.06	1.86
NC	7.31	5.14	1.88	7.32	5.14	1.88
ND	0.94	1.00	0.94	0.94	1.00	0.94
NE	0.96	0.95	0.58	0.96	0.95	0.58
NH	0.00	0.00	0.00	0.00	0.00	0.00
NJ	0.00	0.00	0.00	0.00	0.00	0.00
NM	1.00	1.00	0.01	1.00	1.00	0.01
NV	0.00	0.00	0.00	0.00	0.00	0.00
NY	0.00	0.00	0.00	0.00	0.00	0.00
OH	0.78	0.61	0.29	0.78	0.60	0.29
OK	37.84	4.77	2.54	37.83	4.77	2.54
OR	0.00	0.00	0.00	0.00	0.00	0.00
PA	4.25	4.06	3.94	4.25	4.06	3.94
RI	0.00	0.00	0.00	0.00	0.00	0.00
SC	0.73	1.22	1.76	0.73	1.22	1.76
SD	1.05	1.27	0.00	1.06	1.27	0.00
TN	20.55	1.57	0.00	20.55	1.57	0.00

State Tag	Baseline			Final Rule		
	2028	2030	2035	2028	2030	2035
TXLA[a]	1.86	2.39	2.25	1.86	2.39	2.25
UT	0.93	0.06	0.06	0.93	0.06	0.06
VA	0.11	0.07	0.02	0.11	0.07	0.02
VT	0.00	0.00	0.00	0.00	0.00	0.00
WA	0.00	0.00	0.00	0.00	0.00	0.00
WI	3.50	3.83	1.15	3.51	3.83	1.14
WV	1.40	1.39	1.08	1.40	1.39	1.08
WY	1.26	0.98	0.97	1.26	0.98	0.97

Note: Emissions from Louisiana are less than 10 tpy in the original source apportionment modeling. Air quality impacts and emissions from Texas and Louisiana were combined.

[a] TXLA: Louisiana and Texas

Table A-9 Primary $PM_{2.5}$ Scaling Factors for Coal EGU Tags in the Baseline and the Final Rule

	Baseline			Final Rule		
State Tag	2028	2030	2035	2028	2030	2035
AL	1.20	1.31	1.43	1.20	1.31	1.43
AR	20.02	7.10	3.14	19.96	7.12	3.14
AZ	0.38	1.17	0.61	0.38	1.17	0.61
CA	0.24	0.36	0.16	0.24	0.36	0.16
CO	13.37	1.19	0.51	13.38	1.19	0.51
CT	0.00	0.00	0.00	0.00	0.00	0.00
DC	0.00	0.00	0.00	0.00	0.00	0.00
DE	0.00	0.00	0.00	0.00	0.00	0.00
FL	1.40	1.84	0.25	1.38	1.82	0.25
GA	0.03	0.06	0.00	0.03	0.06	0.00
IA	1.17	1.14	0.67	1.17	1.14	0.67
ID	0.00	0.00	0.00	0.00	0.00	0.00
IL	1.17	0.95	0.57	1.15	0.95	0.57
IN	1.28	0.60	0.20	1.28	0.60	0.20
KY	1.30	1.19	0.77	1.28	1.17	0.75
MA	0.00	0.00	0.00	0.00	0.00	0.00
MD	3.54	3.54	3.54	3.54	3.54	3.54
ME	0.00	0.00	0.00	0.00	0.00	0.00
MI	0.83	0.00	0.00	0.83	0.00	0.00
MN	3.50	2.70	0.00	3.51	2.70	0.00
MO	3.04	1.33	0.54	2.78	1.33	0.54
MS	4.02	3.60	1.06	3.33	2.99	0.88
MT	0.98	0.98	0.98	0.71	0.71	0.72
NC	21.57	17.32	6.08	21.44	17.30	6.09
ND	0.94	0.98	0.78	0.94	0.98	0.78
NEKS[a]	3.70	3.68	0.80	3.70	3.68	0.80
NH	0.00	0.00	0.00	0.00	0.00	0.00
NJ	0.00	0.00	0.00	0.00	0.00	0.00
NM	0.98	0.99	0.01	0.98	0.99	0.01
NV	0.00	0.00	0.00	0.00	0.00	0.00
NY	0.00	0.00	0.00	0.00	0.00	0.00
OH	0.83	1.08	0.19	0.83	1.08	0.19
OK	14.75	8.14	8.94	14.74	8.12	8.94
OR	0.00	0.00	0.00	0.00	0.00	0.00
PA	3.12	3.04	2.28	2.98	2.91	2.15
RI	0.00	0.00	0.00	0.00	0.00	0.00
SC	1.03	2.17	3.78	1.03	2.17	3.78
SD	0.93	1.11	0.00	0.93	1.11	0.00

	Baseline			Final Rule		
State Tag	2028	2030	2035	2028	2030	2035
TN	16.88	1.00	0.00	16.88	1.00	0.00
TXLA[b]	1.10	1.30	1.15	1.10	1.30	1.15
UT	2.92	0.06	0.06	2.92	0.06	0.06
VA	0.46	0.29	0.08	0.46	0.29	0.08
VT	0.00	0.00	0.00	0.00	0.00	0.00
WA	0.00	0.00	0.00	0.00	0.00	0.00
WI	2.11	2.36	0.46	2.13	2.36	0.46
WV	1.29	1.45	1.23	1.22	1.38	1.17
WY	1.03	1.10	1.08	1.02	1.09	1.07

Note: Emissions from Louisiana and Kansas are less than 10 tpy in the original source apportionment modeling. Air quality impacts and emissions from those states were combined with nearby states.

[a] NEKS: Nebraska and Kansas

[b] TXLA: Louisiana and Texas

Table A-10 Primary $PM_{2.5}$ Scaling Factors for Gas EGU Tags in the Baseline and the Final Rule

	Baseline			Final Rule		
State Tag	**2028**	**2030**	**2035**	**2028**	**2030**	**2035**
AL	0.85	0.84	0.71	0.85	0.84	0.71
AR	0.63	0.82	0.43	0.63	0.82	0.43
AZ	0.70	0.85	0.86	0.70	0.85	0.86
CA	0.96	1.06	0.98	0.96	1.06	0.98
CO	1.23	0.74	0.77	1.23	0.74	0.77
CT	0.78	0.67	0.60	0.78	0.67	0.60
DC	0.15	0.13	0.11	0.15	0.13	0.11
DE	0.62	0.64	0.31	0.62	0.64	0.31
FL	0.97	0.98	0.95	0.97	0.98	0.95
GA	0.84	0.81	0.72	0.84	0.81	0.72
IA	0.50	0.48	0.20	0.51	0.47	0.20
ID	1.22	1.65	1.68	1.22	1.65	1.67
IL	0.49	0.55	0.28	0.49	0.55	0.28
IN	0.67	0.67	0.44	0.67	0.67	0.44
KS	1.12	1.02	0.19	1.12	1.02	0.19
KY	0.75	0.72	0.49	0.74	0.72	0.49
LA	0.79	0.80	0.64	0.79	0.80	0.64
MA	0.48	0.46	0.34	0.48	0.46	0.34
MD	1.05	1.08	0.85	1.05	1.09	0.85
ME	1.75	1.44	0.51	1.75	1.44	0.52
MI	0.75	0.87	0.63	0.75	0.87	0.63
MN	0.57	0.52	0.21	0.57	0.52	0.21
MO	0.30	0.33	0.10	0.30	0.33	0.10
MS	0.88	0.84	0.51	0.88	0.85	0.51
MT	0.17	0.21	0.03	0.17	0.21	0.04
NC	0.87	0.70	0.76	0.87	0.69	0.76
ND	0.47	0.92	0.19	0.46	0.91	0.19
NE	2.17	2.04	0.27	2.17	2.04	0.28
NH	0.59	0.43	0.31	0.59	0.43	0.31
NJ	0.82	0.84	0.52	0.82	0.84	0.52
NM	0.52	0.52	0.89	0.52	0.52	0.89
NV	0.72	0.84	0.83	0.72	0.84	0.83
NY	0.86	0.85	0.59	0.86	0.85	0.59
OH	0.95	0.95	0.89	0.95	0.95	0.89
OK	1.00	0.79	0.22	1.01	0.79	0.22
OR	3.29	0.74	0.39	3.30	0.74	0.39
PA	0.83	0.80	0.60	0.83	0.80	0.60

	Baseline			Final Rule		
State Tag	2028	2030	2035	2028	2030	2035
RI	0.83	0.78	0.65	0.83	0.78	0.65
SC	0.80	0.86	0.64	0.80	0.86	0.64
SD	0.73	0.73	0.25	0.73	0.73	0.25
TN	1.08	1.05	0.88	1.08	1.05	0.88
TX	0.90	0.83	0.45	0.90	0.83	0.45
UT	0.66	0.87	0.84	0.66	0.87	0.84
VA	0.81	0.73	0.47	0.81	0.73	0.48
VT	0.00	0.00	0.03	0.00	0.00	0.03
WA	0.44	0.48	0.58	0.44	0.48	0.58
WI	0.56	0.66	0.43	0.56	0.66	0.42
WV	0.51	0.38	0.10	0.51	0.38	0.10
WY	0.01	0.04	0.03	0.01	0.04	0.04

Table A-11 Scaling Factors for Other EGU Tags in the Baseline and the Final Rule

	Baseline			Final Rule		
Pollutants	**2028**	**2030**	**2035**	**2028**	**2030**	**2035**
Seasonal NO_X	1.16	1.16	1.10	1.16	1.16	1.10
Annual NO_X	1.17	1.17	1.11	1.17	1.17	1.11
Annual SO_2	1.00	1.01	1.00	1.00	1.01	1.00
Annual $PM_{2.5}$	1.37	1.37	1.32	1.37	1.37	1.32

A.5 Air Quality Surface Results

The spatial fields of model-predicted air quality changes between the baseline and the two regulatory options in 2028, 2030, and 2035 for AS-MO3 are presented in Figure A-8. It is important to recognize that ozone is a secondary pollutant, meaning that it is formed through chemical reactions of precursor emissions in the atmosphere. As a result of the time necessary for precursors to mix in the atmosphere and for these reactions to occur, ozone can either be highest at the location of the precursor emissions or peak at some distance downwind of those emissions sources. The spatial gradients of ozone depend on a multitude of factors including the spatial patterns of NO_X and VOC emissions and the meteorological conditions on a particular day. Thus, on any individual day, high ozone concentrations may be found in narrow plumes downwind of specific point sources, may appear as urban outflow with large concentrations downwind of urban source locations or may have a more regional signal. However, in general, because the AS-MO3 metric is based on the average of concentrations over more than 180 days in the spring and summer, the resulting spatial fields are rather smooth without sharp gradients, compared to what might be expected when looking at the spatial patterns of MDA8 ozone concentrations on specific high ozone episode days. Air quality changes in these figures are calculated as the final rule minus the baseline. The spatial patterns shown in the figures are a result of (1) the spatial distribution of EGU sources that are predicted to have changes in emissions and (2) the physical or chemical processing that the model simulates in the atmosphere. The spatial fields used to create these maps serve as an input to the benefits analysis and the EJ analysis. While total U.S. NO_X emissions are predicted to decrease in the final rule scenario for 2028 and 2030 when compared to the baseline, predicted NO_X emissions changes are heterogeneous across the country with increases predicted in some states. In 2035, NO_x

emissions across the contiguous 48 states included in this analysis are predicted to increase compared to the baseline. In Figure A-8[126] there are small predicted ozone decreases from the final rule compared to the baseline evident in North Dakota in 2028 and Montana in 2035. There are also small predicted ozone increases from the final rule compared to the baseline evident near the border of Arizona and New Mexico in 2035.

Figure A-9 presents the model-predicted air quality changes between the baseline and the final regulatory option in 2028, 2030, and 2035 for $PM_{2.5}$.[127] Secondary $PM_{2.5}$ species sulfate and nitrate often demonstrate regional signals without large local gradients while primary $PM_{2.5}$ components often have heterogenous spatial patterns with larger gradients near emissions sources. Air quality changes in these figures are calculated as the final rule minus the baseline. The spatial patterns shown are a result of (1) the spatial distribution of EGU sources that are predicted to have changes in emissions and (2) the physical or chemical processing that the model simulates in the atmosphere. The spatial fields used to create these maps serve as an input to the benefits analysis and the EJ analysis. Both secondary and primary $PM_{2.5}$ contribute to the spatial patterns shown in Figure A-9. In 2028, there are predicted $PM_{2.5}$ decreases from the final rule evident in Montana, North Dakota, Missouri, West Virginia, and Pennsylvania. In Montana, West Virginia, and Pennsylvania, these $PM_{2.5}$ changes coincide with predicted decreases in direct $PM_{2.5}$ emissions. In North Dakota and Missouri, emissions of NO_X, SO_2 and direct $PM_{2.5}$ are all predicted to decrease compared to the baseline in 2028. In 2030 and 2035, there are predicted $PM_{2.5}$ decreases from the final rule evident in Montana, West Virginia, and Pennsylvania. In 2030 those predicted $PM_{2.5}$ concentration decreases coincide with direct $PM_{2.5}$ emissions decreases from all three states. In 2035 the predicted $PM_{2.5}$ concentration decreases coincide with SO_2, NO_X, and direct $PM_{2.5}$ decreases from Montana and West Virginia and direct $PM_{2.5}$ decreases from Pennsylvania in 2035.

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[126] Note scale change on maps compared to similar figures from the proposal RIA. Color scale presented in figure 8-8 has a range of -0.11 ppb to 0.11 ppb. Maps in the proposal used a scale range from -0.2 ppb to 0.2 ppb.

[127] Note scale change on maps compared to similar figures from the proposal RIA. Color scale presented in figure 8-9 has a range of -0.011 $\mu g/m^3$ to 0.011 $\mu g/m^3$. Maps in the proposal used a scale range from -0.05 $\mu g/m^3$ to 0.05 $\mu g/m^3$.

Figure A-8 Maps of change in ASM-O3 for the final rule compared to baseline values (ppb) shown in 2028 (right panel), 2030 (middle panel) and 2035 (right panel)

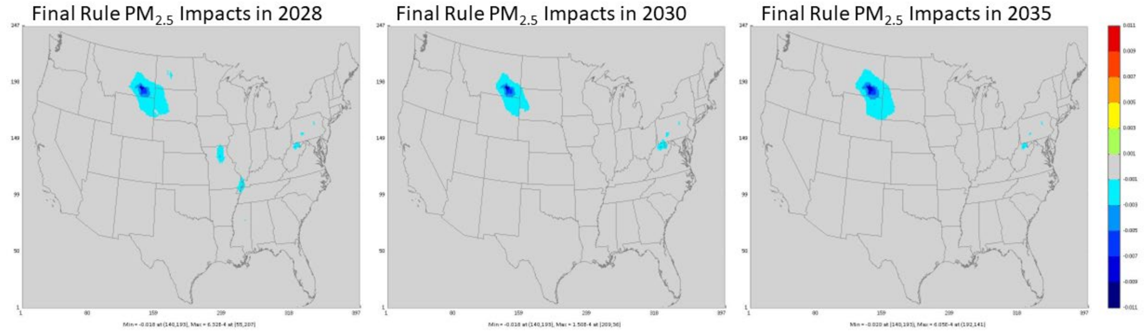

Figure A-9 Maps of change in $PM_{2.5}$ for the final rule compared to baseline values (µg/m3) shown in 2028 (right panel), 2030 (middle panel) and 2035 (right panel)

A.6 Uncertainties and Limitations of the Air Quality Methodology

One limitation of the scaling methodology for creating ozone and $PM_{2.5}$ surfaces associated with the baseline or regulatory control alternatives described above is that the methodology treats air quality changes from the tagged sources as linear and additive. It therefore does not account for nonlinear atmospheric chemistry and does not account for interactions between emissions of different pollutants and between emissions from different tagged sources. The method applied in this analysis is consistent with how air quality estimations have been made in several prior regulatory analyses (U.S. EPA, 2012, 2019, 2020a). We note that air quality is calculated in the same manner for the baseline and for the final rule, so any uncertainties associated with these assumptions are propagated through results for both the baseline and the final rule in the same manner. In addition, emissions changes between baseline and the final rule are relatively small compared to modeled future year emissions that form the basis of the source apportionment approach described in this appendix. Previous studies have shown that air pollutant concentrations generally respond linearly to small emissions changes of up to 30 percent (Cohan et al., 2005; Cohan and Napelenok, 2011; Dunker et al., 2002; Koo et al., 2007; Napelenok et al., 2006; Zavala et al., 2009). A second limitation is that the source apportionment contributions are informed by the spatial and temporal distribution of the emissions from each source tag as they occur in the future year modeled case. Thus, the contribution modeling results do not allow us to consider the effects of any changes to spatial distribution of EGU emissions within a state between the future year modeled case and the baseline and final rule scenarios analyzed in this RIA. Finally, the CAMx-modeled concentrations themselves have some uncertainty. While all models have some level of inherent uncertainty in their formulation and inputs, the base-year 2016 model outputs have been evaluated against ambient measurements and have been shown to adequately reproduce spatially and temporally varying concentrations (U.S. EPA, 2023a, 2024).

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APPENDIX B: CLIMATE BENEFITS APPENDIX

B.1 Climate Benefits Estimated using the Interim SC-CO_2 values used in the Proposal

This appendix presents the climate benefits of the final standards using the interim SC-CO_2 values used in the proposal of this rulemaking. The interim SC-CO_2 values are presented in Table B-1 and the climate benefits using these values are presented in Table B-2.

Table B-1 Interim SC-CO_2 Values, 2028 to 2037 (2019 dollars per metric ton)

Emissions Year	Discount Rate and Statistic			
	5%	3%	2.50%	3%
	Average	Average	Average	95th Percentile
2028	$16	$54	$79	$160
2029	$16	$55	$81	$160
2030	$17	$56	$82	$170
2031	$17	$57	$83	$170
2032	$18	$58	$85	$170
2033	$18	$59	$86	$180
2034	$19	$60	$87	$180
2035	$19	$61	$88	$180
2036	$20	$62	$90	$190
2037	$20	$63	$91	$190

Note: These SC-CO_2 values are identical to those reported in the 2016 SC-GHG TSD (IWG, 2016) adjusted for inflation to 2019 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis' (BEA) NIPA Table 1.1.9 (U.S. BEA, 2021). The values are stated in \$/metric ton CO_2 (1 metric ton equals 1.102 short tons) and vary depending on the year of CO_2 emissions. This table displays the values rounded to the nearest dollar; the annual unrounded values used in the calculations in this RIA are available on OMB's website: *https://www.whitehouse.gov/omb/information-regulatory-affairs/regulatory-matters/#scghgs*.
Source: Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under E.O. 13990 (IWG, 2021).

Table B-2 Stream of Projected Climate Benefits under the Final Rule from 2028 to 2037 (millions of 2019 dollars, discounted to 2023)

Emissions Year	SC-CO_2 Discount Rate and Statistic			
	5%	3%	2.50%	3%
	Average	Average	Average	95th Percentile
2028*	\$0.9	\$3.3	\$5.0	\$10
2029	\$0.9	\$3.3	\$4.9	\$9.9
2030*	-\$0.49	-\$1.8	-\$2.7	-\$5.4
2031	-\$0.48	-\$1.8	-\$2.7	-\$5.4
2032	\$1.3	\$4.8	\$7.2	\$15
2033	\$1.3	\$4.7	\$7.1	\$14
2034	\$1.2	\$4.7	\$7.1	\$14
2035*	\$1.2	\$4.6	\$7.0	\$14
2036	\$1.2	\$4.6	\$6.9	\$14
2037	\$1.2	\$4.5	\$6.9	\$14
PV	**\$8.2**	**\$31**	**\$47**	**\$94**
EAV	**\$1.1**	**\$3.6**	**\$5.3**	**\$11**

Note: Climate benefits are based on reductions in CO_2 emissions and are calculated using the IWG interim SC-CO_2 estimates from IWG (2021).

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