APPENDIX E

Air Quality Modeling and Health Impacts Assessment for Proposed Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks

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ACRONYMS AND ABBREVIATIONS

BenMAP	Environmental Benefits Mapping and Analysis Program
CAFE	Corporate Average Fuel Economy
CAMx	Comprehensive Air Quality Model with Extensions
CMAQ	Community Multiscale Air Quality
CO	carbon monoxide
COI	cost of illness
EGU	electric generating unit
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
GREET	Greenhouse Gas, Regulated Emissions and Energy Used in Transportation
IPM	Integrated Planning Model
LD GHG	Light-duty greenhouse gas
MCIP	Meteorology-Chemistry Interface Processor
MM5	Fifth Generation Mesoscale Model
MOVES	Motor Vehicle Emission Simulator
mpg	miles per gallon
MY	model year
NAAQS	National Ambient Air Quality Standards
NH_3	ammonia
NHTSA	National Highway Traffic Safety Administration
NO_x	oxides of nitrogen
PAVE	Package for Analysis and Visualization of Environmental
PM_{10}	Coarse particulates (particulate matter with an aerodynamic diameter equal to or greater than 10 microns)
$PM_{2.5}$	Fine particulates (particulate matter with an aerodynamic diameter equal to or less than 2.5 microns)
ppb	parts per billion
RIA	Regulatory Impact Analysis
SMOKE	Sparse-Matrix Operator Kernel Emissions
SO_2	sulfur dioxide
VMT	vehicle miles traveled
VOC	volatile organic compound
VSL	value of statistical life
WTP	willingness to pay

Appendix E
Air Quality Modeling and Health Impacts Assessment for Proposed Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks

E.1 INTRODUCTION

This appendix summarizes the application of air quality modeling tools to assess impacts to air quality and the related health effects of NHTSA's proposed CAFE standards. The air quality modeling and health effects analysis focused on ozone and fine particulate matter ($PM_{2.5}$). No air quality modeling of toxic emissions was done as part of this analysis.

E.1.1 Objective

The objective of this study was to use air quality modeling and health-related benefits analysis tools to examine the air quality-related consequences of the Proposed Action and, specifically, to quantify the expected future air quality and health-related benefits associated with the alternative fuel consumption standards NHTSA considered in its Draft EIS[1] (NHTSA 2011a). To support this objective, NHTSA calculated estimates of air quality changes and health-related benefits for the national scale, based on a detailed analysis of air quality and health effects throughout the contiguous 48 states.

Different regions of the country could experience either a net increase or a net decrease in emissions due to the Proposed Action, depending on the relative magnitudes of the changes in emissions due to increased fuel economy, increased vehicle use, and reduced fuel production and distribution. The EIS air quality analysis accounts for regional differences through the use of grid-based air quality modeling and analysis techniques, which account for local and regional differences in emissions and many of the other factors (such as meteorology and atmospheric processes) that affect air quality and the resulting health effects at any given location.

E.1.2 Overview of the Methodology

To examine and quantify the air quality and health-related benefits associated with implementing the Proposed Action and alternatives, NHTSA performed a national-scale photochemical air quality modeling and health risk assessment, the key components of which were:

- Preparing emission inventories
- Modeling air quality
- Assessing health impacts

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[1] To accommodate the substantial time required to complete the air quality modeling analysis, NHTSA initiated air quality modeling before the inputs and emissions forecasts for the Final EIS were finalized. Therefore, NHTSA used the Draft EIS inputs and emissions forecasts for the analysis in this report.

The primary tools used for this assessment were:

- Sparse-Matrix Operator Kernel Emissions (SMOKE) processing tool (version 2.7) to prepare model-ready emissions
- Community Multiscale Air Quality (CMAQ) model (version 4.7) to quantify air quality changes for the different fuel economy alternatives
- Environmental Benefits Mapping and Analysis Program (BenMAP) tool (version 4.0.43) to assess the health-related impacts of the simulated changes in air quality

These tools are widely used in air quality and health effects analyses.

The national-scale modeling analysis employed the standard CMAQ continental modeling domain, shown in Figure E.1.2-1. The horizontal resolution of the grid for this modeling domain is 36 kilometers (22.4 miles). Air quality and health-related impacts were calculated for each grid cell within the entire conterminous United States (48 states). Although the modeling domain does not include all 50 states, nearly all of the affected emissions and population are included in the domain; therefore, the results represent those for a national-scale analysis.

NHTSA applied the CMAQ model for an annual simulation period using meteorological inputs for a base year of 2005. EPA provided the meteorological inputs used for this study, and is currently using these inputs for a number of other air quality modeling studies.

Modeling was performed for the year 2030 and the results were used to examine the Preferred Alternative and alternatives considered in the Draft EIS. NHTSA chose 2030 for analysis because a large proportion of vehicles in operation are expected to meet the level of the standards set forth for MY 2025 standards by 2030. In addition, up-to-date emissions data were available from EPA for 2030. EPA provided the latest projected 2030 national-scale emissions inventory. The emissions were processed for the 36-kilometer modeling domain using SMOKE. The resulting model-ready inventories contain emissions for all criteria pollutants (as required for photochemical modeling) for multiple source category sectors, including on-road mobile sources, non-road mobile sources (e.g., construction equipment, locomotives, ships, and aircraft), electric generating unit (EGU) point sources, non-EGU point sources, area sources, and biogenic sources.

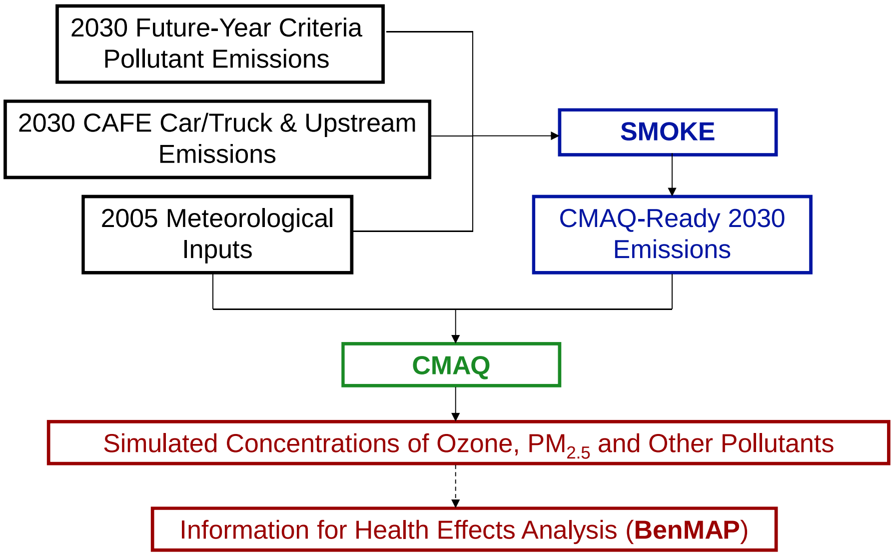
Figure E.1.2-1. CMAQ Modeling Domain for the NHTSA CAFE Air Quality Modeling Analysis (Horizontal Grid Spacing is 36 kilometers [22.4 miles])

Following preparation of baseline 2030 emissions inventories, the baseline emissions for the passenger car and light truck portion of the on-road mobile emissions and the relevant upstream categories were replaced with data reflecting the alternatives analyzed in the Draft EIS. NHTSA calculated national estimates of on-road emissions for these vehicle classes for 2030 (NHTSA 2011a) using the Motor Vehicle Emission Simulator (MOVES) model. NHTSA also estimated upstream emissions associated with the fuels used by these vehicle classes (NHTSA 2011a) using emission factors provided by EPA, based on the Greenhouse Gas, Regulated Emissions and Energy Used in Transportation (GREET) model (Argonne 2002), which contains data on emissions intensities (amount of pollutant emitted per unit of electrical energy generated) through 2020. To project the national average electricity generating fuel mix for the reference year 2020, NHTSA used the National Energy Modeling System (NEMS) 2011 version, an energy-economy modeling system from the U.S. Department of Energy.

NHTSA then applied CMAQ for each alternative, using the emissions specific to each alternative. The simulated difference in air quality between the No Action Alternative and each action alternative represents the change in air quality associated with that alternative. Following the application of CMAQ, NHTSA processed the CMAQ outputs for input to the BenMAP health effects analysis tool, and used BenMAP to estimate the health impacts and monetized health-related benefits associated with the changes in air quality simulated by CMAQ for each of the action alternatives. The BenMAP tool includes health impact functions, which relate a change in the concentration of a pollutant with a change in the incidence of a health endpoint. BenMAP also calculates the economic value of health impacts. For this study, the health effects analysis considered the effects of ozone and fine particulate matter ($PM_{2.5}$). Health impacts directly associated with changes in SO_2, CO and other emissions were not estimated using BenMAP. Health effects were calculated for the national scale.

Figure E.1.2-2 shows the components of the NHTSA air quality modeling and health-related benefits analysis. Note that both the emissions and meteorological inputs are used by SMOKE.

Figure E.1.2-2. Schematic Diagram of the NHTSA CAFE Standards Air Quality Modeling and Health-related Benefits Analysis



E.1.3 Model Applications

NHTSA designed the modeling analysis to examine the potential impacts on air quality under four alternative approaches to regulating light-duty vehicle fuel economy for MYs 2017–2025, including a Preferred Alternative and a No Action Alternative. The modeling analysis examines direct and indirect impacts under two distinct sets of assumptions, as discussed in detail in the Draft EIS (NHTSA 2011a), and cumulative impacts. The direct and indirect impacts analyses are referred to as Analysis A and Analysis B, as defined below.

Direct and Indirect Impacts, Analysis A: The Analysis A No Action Alternative assumes that, in the absence of the Proposed Action, the baseline light-duty vehicle fleet in MYs 2017–2025 and beyond will attain an average fleetwide fuel economy no higher than that required under the agencies' MY 2016 standards established by final rule in April 2010. In addition, Analysis A assumes that fleetwide fuel economy under the action alternatives will be no higher than the minimum necessary to comply with the level of the agency's CAFE standard for a particular year during the rulemaking period. Finally, after MY 2025, it assumes that average fleetwide fuel economy under the action alternatives will never exceed the level set forth for the MY 2025 standards.

Direct and Indirect Impacts, Analysis B: The Analysis B No Action Alternative assumes that, in the absence of the Proposed Action, the average fleetwide fuel economy of passenger cars and light trucks will continue to increase beyond the level necessary to meet the MY 2016 standards. In addition, this analysis reflects action alternatives that assume that once manufacturers comply with the CAFE standard for a particular year during the MY 2017-2025 period, they would consider making further improvements in fuel economy if it is cost-effective to do so. Finally, Analysis B assumes that average fleetwide fuel economy after MY 2025 under the action alternatives will continue to increase beyond the levels necessary to meet the MY 2025 standards as set forth by the agency.

NHTSA also examined cumulative impacts, as defined below.

Cumulative Impacts: The No Action Alternative assumes that the baseline light-duty vehicle fleet in MYs 2017 and beyond would attain an average fleetwide fuel economy no higher than that required under the agencies' MY 2016 standards. The action alternatives under the cumulative impacts analysis assume that once manufacturers comply with the CAFE standard for a particular year during the MY 2017-2025 period, they would consider making further improvements in fuel economy if it is cost-effective to do so. In addition, the analysis assumes continued increases in fuel economy for all action alternatives after 2025 that result directly or indirectly from the proposed rule in addition to reasonably foreseeable improvements in fuel economy caused by other actions.

For each of these analyses, NHTSA considered four alternatives, as follows:

- Alternative 1 (No Action).
- Alternative 2: Two percent average annual fleetwide increase in fuel economy for both passenger cars and light trucks for MYs 2017–2025. Alternative 2 represents the lower bound of the range of average annual stringency increases NHTSA believes includes the maximum feasible stringency.
- the Preferred Alternative: Approximately 4 percent average annual fleetwide increase in fuel economy. Specifically, as set forth in the Draft EIS, under the Preferred Alternative, manufacturers would be required to meet an estimated average fleetwide fuel economy level of 40.9 mpg in MY 2021 and, as set forth for the second phase of the program, 49.6 mpg for MY 2025. For passenger cars, the annual rates of increase in the average of fuel economy levels required of manufacturers (and based on projected production volumes) between MYs 2017 and 2021 averages 4.1 percent. For light trucks, the proposed annual rate of increase in MYs 2017 through 2021 averages 2.9 percent per year. In the second phase of the program (MYs 2022–2025), the annual increase for passenger cars would be expected to average 4.3 percent, and for light trucks, 4.7 percent.
- Alternative 4: Seven percent average annual fleetwide increase in fuel economy for both passenger cars and light trucks for MYs 2017–2025. Alternative 4 represents the upper bound of the range of average annual stringency increases NHTSA believes includes the maximum feasible stringency.

For each analysis, NHTSA calculated the health effects and monetized health effects associated with each alternative in relation to the baseline of the No Action Alternative for that analysis.

E.2 EMISSION INVENTORY PREPARATION

This section summarizes the data, methods, and procedures used to prepare modeling emission inventories for use in the air quality modeling analysis of the Proposed Action. The analysis examined the expected changes in criteria pollutant emissions from on-road mobile sources for the alternatives and from the effects those alternatives would have on emissions associated with various upstream activities related to the extraction of oil (feedstock recovery); feedstock transportation; fuel refining; and fuel transportation, storage, and distribution. The emission changes were incorporated into a national air quality modeling database originally developed by EPA, and the impacts were assessed for an annual simulation period. Although the Draft EIS (NHTSA 2011a) evaluated changes in emissions for a number of future years, the emission preparation and modeling analysis discussed in this analysis focuses on the year 2030.

E.2.1 Emissions Data and Methods

The CMAQ model requires as hourly input, gridded criteria pollutant emissions of both anthropogenic and biogenic sources that have been spatially allocated to the appropriate grid cells and chemically speciated for the chemical mechanism used in the model. NHTSA processed and prepared the modeling inventories for CMAQ using EPA's SMOKE software (version 2.7) (CEMPD 2010). NHTSA derived the emission inventories prepared for the modeling analysis for all sectors, in part, from information developed by EPA for their 2030 light-duty vehicle greenhouse gas (LD GHG) analysis based on the 2005 modeling platform database. The SMOKE emission input files include the following categories:

- On-road mobile sources
- Non-road sources
- EGU sources (estimated using the Integrated Planning Model [IPM] and referred to as IPM point sources)
- Non-EGU (non-IPM) point sources, including aircraft emissions
- Non-point (area) sources
- Agricultural sources
- Category 3 (C3) commercial marine vessels
- Locomotives and commercial marine except for C3 commercial marine vessels
- Area fugitive dust sources
- Average-year wildfire and prescribed fire

NHTSA obtained the SMOKE emission input files from EPA for the 2030 future assessment case for the LD GHG 2017–2025 analysis. These files included emissions data and related information for the 50 states and Washington, DC, along with the emissions for the portions of Canada, Mexico, and offshore areas included in the modeling domain. In addition, NHTSA obtained the SMOKE input files for biogenic sources for 2005 (the meteorological base year) for the modeling domain from EPA. The modeling inventories include the following pollutants: volatile organic compounds (VOCs), oxides of nitrogen (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), and ammonia (NH_3).

NHTSA calculated the expected changes in on-road mobile emissions (for passenger cars and light trucks) and upstream emissions associated with these vehicle classes (NHTSA 2011a). For each pollutant, total emissions for all states and Washington, DC, was provided for passenger car and light truck "tailpipe" emissions and for the upstream emissions associated with fuel production for these vehicle classes for the No Action Alternative and the action alternatives. NHTSA also calculated estimates of vehicle miles traveled (VMT) by county for 2030. As part of the emissions processing, NHTSA incorporated this information into the modeling input files for each simulation, as detailed in Section E.2.2.

E.2.2 Emissions Processing Procedures

As noted previously, NHTSA used SMOKE version 2.7 to process the emissions and prepare CMAQ-ready inputs for the alternatives using source sector files and other emission information. Preparation of the various modeling inventories included (1) processing the emissions for all source sectors using the SMOKE programs and inputs, (2) substituting the on-road mobile and upstream emissions to reflect the No Action Alternative and other alternatives, and (3) reviewing and performing quality assurance checks.

E.2.2.1 Preparation of On-road Mobile Emission Inputs

The SMOKE on-road mobile input files contain monthly, county-level emissions for criteria pollutants by vehicle type and roadway type. Table E.2.2.1-1 lists the vehicle types.

Table E.2.2.1-1. Vehicle Types in EPA's SMOKE Input Files for On-road Mobile Sources

Class #	Vehicle Class	Description
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1	Light-Duty Gasoline Trucks 1 (0–6,000 lbs. gross vehicle weight rating [GVWR], 0–3,750 lbs. loaded vehicle weight [LVW])
3	LDGT2	Light-Duty Gasoline Trucks 2 (0–6,000 lbs. GVWR, 3,751–5,750 lbs. LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001–8,500 lbs. GVWR, 0–5,750 lbs. adjusted load vehicle weight [ALVW])
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001–8,500 lbs. GVWR, > 5,751 lbs. ALVW)
6	HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8,501–10,000 lbs. GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001–14,000 lbs. GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001–16,000 lbs. GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001–19,500 lbs. GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501–26,000 lbs. GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001–33,000 lbs. GVWR)
12	HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001–60,000 lbs. GVWR)
13	HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12	Light-Duty Diesel Trucks 1 and 2 (0–6,000 lbs. GVWR)
16	HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8,501–10,000 lbs. GVWR)
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001–14,000 lbs. GVWR)
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001–16,000 lbs. GVWR)
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001–19,500 lbs. GVWR)
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501–26,000 lbs. GVWR)
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001–33,000 lbs. GVWR)
22	HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001–60,000 lbs. GVWR)
23	HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
24	MC	Motorcycles (Gasoline)
25	HDGB	Gasoline Buses (School, Transit, and Urban)
26	HDDBT	Diesel Transit and Urban Buses
27	HDDBS	Diesel School Buses
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001–8,500 lbs. GVWR)

Table E.2.2.1-2 lists the various roadway types.

Table E.2.2.1-2. Roadway Types in EPA's SMOKE Input Files for On-road Mobile Sources

Area Type	Description
Rural	Interstate
Rural	Other Principal Arterial
Rural	Minor Arterial
Rural	Minor Collector
Rural	Major Collector
Rural	Local
Urban	Interstate
Urban	Other Principal Arterial
Urban	Minor Arterial
Urban	Minor Collector
Urban	Major Collector
Urban	Local

The SMOKE on-road mobile emission files include emissions for exhaust, evaporation, tires, and brakes. Exhaust emissions are provided for VOCs, NO_x, CO, SO_2, $PM_{2.5}$, PM_{10}, and NH_3. Evaporative emissions are provided for VOCs. For tire and brake wear, emissions are provided for $PM_{2.5}$ and PM_{10}.

The Proposed Action applies only to passenger cars and light trucks. As shown in Table E.2.2.1-1 and as defined in EPA's MOBILE6 motor vehicle emission factor model, the passenger-car category is made up of the following vehicle classes: Classes 1, light-duty gas vehicle, and 14, light-duty diesel vehicle. The light-duty truck category comprises various vehicle classes depending on size: Classes 2, light-duty gas truck; 3, light-duty gas truck 2; 4, light-duty gas truck 3; and 5, light-duty gas truck 4; and two light-duty diesel truck categories: Classes 15, light-duty diesel truck 12 and light-duty diesel truck 28, and light-duty diesel truck 34.

To incorporate the NHTSA emission estimates for each alternative into the emission input files, NHTSA modified the SMOKE mobile source input files such that the NHTSA-specific emissions were substituted for the light-duty vehicle categories to create modified SMOKE input files. The steps involved in this process are as follows:

Step 1 – Calculate the county-level car and light-truck tailpipe emissions for the alternatives, for the NHTSA emission estimates.

With the total U.S. emissions for passenger cars and light trucks for NO_x, VOCs, CO, SO_2 and $PM_{2.5}$ for each alternative and the VMT fractions for all U.S. counties, allocate county-level emissions for each pollutant.

Step 2 – Calculate the county-level total emissions based on the EPA 2030 SMOKE input files for the on-road mobile sector.

- With the utility program *mb_cty_sum*, calculate the monthly total county-level passenger car and light-truck emissions for the EPA 2030 on-road mobile input files.
- With the utility program *cty_ann_ems*, calculate the annual county-level passenger car and light-truck emissions based on the monthly totals.

Step 3 – Calculate adjustment factors for passenger cars and light trucks for the alternatives.

- With the utility program *cal_fac*, calculate the ratio of county-level emissions from a specified alternative to the EPA 2030 on-road mobile emissions.

Step 4 – Apply the adjustment factors for passenger cars and light trucks to the 2030 on-road mobile SMOKE input file for each alternative.

- With the utility program *adj_ems*, apply the county-level adjustment factors for passenger cars and light trucks for a specified alternative to the EPA 2030 on-road mobile SMOKE input files to prepare updated SMOKE input files.

E.2.2.2 Preparation of Upstream Emission Inputs

As noted above, the Proposed Action is also expected to affect the upstream emissions associated with the extraction of oil (feedstock recovery); feedstock transportation; fuel refining; and fuel transportation, storage, and distribution. The upstream emissions are associated with a variety of equipment, processes, and activities involved in the production of fuel, including oil-field extraction equipment (e.g., drills and pumps); oil refining (e.g., boilers and heaters); and transportation, storage, and distribution of the fuel. For this analysis, EPA provided a list of Source Classification Codes associated with these activities and equipment types and a complete list of refineries operating in the United States. For each alternative, NHTSA estimated upstream emissions for each pollutant, for passenger cars and light trucks only. However, the EPA SMOKE input files for 2030 contain emissions for all vehicle types, not just passenger cars and light trucks. To utilize and incorporate the NHTSA upstream emissions estimates into the EPA SMOKE files, it was assumed that 50 percent of the total upstream emissions are associated with the production of fuel for passenger cars and light trucks (EPA 2010a). Using the refinery list and Source Classification Codes provided by EPA for all assumed sources and source types associated with upstream emissions, NHTSA substituted estimates of the emissions associated with the alternatives for the corresponding EPA emissions to prepare modified SMOKE inputs for the non-point and non-IPM point emissions.

Regarding upstream emissions for each alternative, NHTSA considered only emissions occurring domestically and did not consider emissions from the transport of crude oil to the United States or refining and transportation of foreign finished fuel to the United States. The upstream emissions estimates assumed that 50 percent of the fuel savings from the alternatives would reduce imports of refined gasoline, since 50 percent of light-duty vehicle gasoline is refined outside of the United States. Therefore this reduction would lower domestic emissions only during fuel transportation, storage, and distribution and would not reduce emissions from feedstock recovery, feedstock transportation, and fuel refining. The upstream emissions estimates also assumed that 90 percent of the reduction in domestic fuel refining would reduce imports of crude petroleum since only 10 percent of crude oil refined to produce gasoline is extracted domestically (and therefore would not reduce domestic emissions from feedstock recovery and feedstock transportation), and that 10 percent of the reduction in domestic fuel refining would reduce domestic production of crude petroleum (which would reduce domestic emissions from feedstock recovery and feedstock transportation). NHTSA estimated these percentages using several scenarios from the Energy Information Administration Annual Energy Outlook 2008 (EIA 2008). The upstream emissions also included changes associated with the generation of electricity for use in electric and plug in electric vehicles. Although the changes in emissions due to an increase in electric vehicles were included as part of the upstream emissions they were not applied directly to specific EGU sources. These changes account for a small portion of the overall emissions changes on the national level.

E.2.2.3 SMOKE Emission Processing and Quality Assurance Procedures

Once the modified mobile source and upstream-related SMOKE input files reflecting the action alternatives were developed, the files were processed by SMOKE and merged with the other source category input files to prepare model-ready inputs for CMAQ. The general procedures followed in preparing the modeling inventories, using various programs included with SMOKE, were as follows:

- Modify on-road mobile source SMOKE input files using emissions data and related information
- Modify upstream-related SMOKE input files using emissions data and related information
- Chemically speciate input criteria pollutants into the Carbon Bond 2005 chemical mechanism species, as required by CMAQ
- Temporally distribute the input annual and monthly emissions into hourly emissions
- Spatially distribute input emissions to the modeling grid
- Merge emissions from all source categories into the CMAQ model-ready files
- Review and ensure the quality of the inventory processing procedures and results

The emission inventory processing quality assurance procedures included the development and examination of tabular emission summaries and graphical display products. Tabular summaries were prepared to examine emission totals for various steps of emissions processing. Summaries for input emissions are based on the input inventory data: monthly emissions for the on-road and non-road mobile sectors, and annual emissions for other sectors for criteria pollutants. Summaries for output emissions are based on the SMKMERGE reports – daily emissions for each species included in the chemical mechanism for each sector. The output daily emissions are summed over all days in the year and the species are summed for the criteria pollutants. The emissions were summarized for each alternative by state and sector, and comparisons were made between the input emissions and output emissions for each sector to ensure consistency.

In addition to the tabular summaries, various graphical displays were prepared for one day of each month (the 15th of each month was randomly selected) to examine the spatial distribution and temporal variation for each sector and the final merged emissions using the Package for Analysis and Visualization of Environmental (PAVE) data graphical plotting package, available from the University of North Carolina Institute for the Environment web site at http://www.ie.unc.edu/cempd/EDSS.

E.2.3 Emission Summaries

As described in Section E.1, for this air quality analysis, NHTSA modeled four alternatives under the three analyses reported in the Draft EIS (Direct and Indirect Impacts, Analysis A; Direct and Indirect Impacts, Analysis B; and Cumulative Impacts). The alternatives simulated under these analyses include the No Action Alternative (Alternative 1), and Alternatives 2, 3, and 4, which required the preparation of 12 modeling emission inventories. As described in Chapter 2 of the EIS, the Cumulative Impacts No Action Alternative is equivalent to the No Action Alternative under Analysis A, and Cumulative Impacts Alternatives 2 through 4 are equivalent to the corresponding Analysis B alternatives.

Using the original and modified inputs, NHTSA used the SMOKE emissions processing system to prepare the CMAQ model-ready hourly emission inventory inputs for each simulation for the 36-kilometer (22.4-mile) resolution national grid. Although the processed emission inventories were prepared for the full list of emission species given in Section E.2.2.1, most of the presentation and discussion that follows focuses on VOC, NO_x, SO_2, and primary $PM_{2.5}$ emissions.

Table E.2.3-1 lists national (48-state) annual emission totals for each pollutant by sector for each alternative and analysis simulated. Table E.2.3-2 lists annual emission totals for all sectors combined for the alternatives and analyses. The emission totals reflect the expected emission reductions from upstream sources and on-road motor vehicles based on the stringency of the alternatives. However, for example, NO_x emissions from on-road motor vehicles under Analysis B Alternative 4 are slightly higher than NO_x emissions under Analysis B Alternative 3, reflecting the fuel economy rebound effect assumptions incorporated into the emission inventories, as detailed in Chapter 2 of the EIS.

The tables and figures in this appendix abbreviate the modeling analyses as follows: Direct and Indirect Impacts, Analysis A appears as DI/A; Direct and Indirect Impacts, Analysis B appears as DI/B; and Cumulative Impacts appears as CI.

To illustrate and check the reasonableness of the spatial distribution of emissions throughout the modeling domain, NHTSA prepared and examined daily emission density plots for selected days. NHTSA used emissions associated with the No Action Alternative to check the reasonableness of the spatial distribution of emissions. Figures E.2.3-1(a)-(d) show daily emissions for July 15th for VOCs, NO_x, SO_2, and $PM_{2.5}$ for the 36-kilometer (22.4-mile) resolution national grid. The date and time given on this and all subsequent figures refer to the meteorological base year (2005) and start hour for the selected day or averaging period. The minimum and maximum values for any location in the domain are also provided, along with their grid cell (x,y) locations. NHTSA selected a summer day for display because it is included in both the ozone season and the annual simulation period. The plots show the spatial distribution of 2030 emissions under the No Action Alternative for Analysis A, with higher emissions in the more populated areas of the eastern United States and California, and lower emissions in the less-populated areas of the interior western United States and areas of Canada and Mexico. The VOC emission plots also include biogenic emissions, with higher emissions associated with the more forested regions of the southeastern United States and Canada. The $PM_{2.5}$ emissions are associated with various anthropogenic mobile and industrial sources, and agricultural burning and wildfires.

Table E.2.3-1. National (48-state) Emission Totals (thousands tons/year) by Sector for the NHTSA 2030 Modeling Analyses and Alternatives

		No Action			Alternative 2			Alternative 3			Alternative 4		
Pollutant	Sector	DI/A	DI/B	CI	DI/A	DI/B	CI	DI/A	DI/B	CI	DI/A	DI/B	CI
VOCs	EGU	52	52	52	52	52	52	52	52	52	52	52	52
	Non-EGU Point	1,045	1,045	1,045	1,042	1,041	1,041	1,039	1,039	1,039	1,035	1,034	1,034
	Nonpoint	8,158	8,152	8,158	8,122	8,119	8,119	8,093	8,091	8,091	8,051	8,046	8,046
	Nonroad	1,297	1,297	1,297	1,297	1,297	1,297	1,297	1,297	1,297	1,297	1,297	1,297
	On-road Vehicle	1,137	1,138	1,137	1,141	1,142	1,142	1,140	1,140	1,140	1,123	1,121	1,121
NO_x	EGU	1,913	1,913	1,913	1,913	1,913	1,913	1,913	1,913	1,913	1,913	1,913	1,913
	Non-EGU Point	1,972	1,971	1,972	1,966	1,966	1,966	1,964	1,963	1,963	1,962	1,962	1,962
	Nonpoint	1,789	1,785	1,789	1,770	1,768	1,768	1,760	1,759	1,759	1,754	1,753	1,753
	Nonroad	1,624	1,624	1,624	1,624	1,624	1,624	1,624	1,624	1,624	1,624	1,624	1,624
	On-road Vehicle	1,761	1,762	1,761	1,771	1,772	1,772	1,782	1,785	1,785	1,779	1,786	1,786
CO	EGU	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056
	Non-EGU Point	2,960	2,960	2,960	2,958	2,958	2,958	2,957	2,957	2,957	2,958	2,957	2,957
	Nonpoint	15,051	15,050	15,051	15,046	15,045	15,045	15,044	15,044	15,044	15,045	15,045	15,045
	Nonroad	14,727	14,727	14,727	14,727	14,727	14,727	14,727	14,727	14,727	14,727	14,727	14,727
	On-road Vehicle	19,472	19,501	19,472	19,652	19,673	19,673	19,560	19,573	19,573	18,779	18,664	18,664
SO_2	EGU	2,135	2,135	2,135	2,135	2,135	2,135	2,135	2,135	2,135	2,135	2,135	2,135
	Non-EGU Point	1,529	1,526	1,529	1,515	1,514	1,514	1,512	1,511	1,511	1,528	1,528	1,528
	Nonpoint	1,186	1,186	1,186	1,186	1,186	1,186	1,186	1,186	1,186	1,186	1,186	1,186
	Nonroad	17	17	17	17	17	17	17	17	17	17	17	17
	On-road Vehicle	30	30	30	27	27	27	25	25	25	23	22	22
PM_{10}	EGU	302	302	302	302	302	302	302	302	302	302	302	302
	Non-EGU Point	622	621	622	619	619	619	618	618	618	618	618	618
	Nonpoint	10,986	10,986	10,986	10,986	10,986	10,986	10,986	10,986	10,986	10,986	10,986	10,986
	Nonroad	103	103	103	103	103	103	103	103	103	103	103	103
	On-road Vehicle	100	100	100	100	100	100	100	100	100	100	100	100
$PM_{2.5}$	EGU	239	239	239	239	239	239	239	239	239	239	239	239
	Non-EGU Point	413	413	413	411	410	410	409	409	409	409	409	409
	Nonpoint	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710	2,710
	Nonroad	95	95	95	95	95	95	95	95	95	95	95	95
	On-road Vehicle	89	89	89	90	90	90	89	89	89	87	87	87
NH_3	EGU	49	49	49	49	49	49	49	49	49	49	49	49
	Non-EGU Point	162	162	162	162	162	162	162	162	162	162	162	162
	Nonpoint	3,872	3,872	3,872	3,872	3,872	3,872	3,872	3,872	3,872	3,872	3,872	3,872
	Nonroad	4	4	4	4	4	4	4	4	4	4	4	4
	On-road Vehicle	95	95	95	95	95	95	95	95	95	95	95	95

Table E.2.3-2. National (48-state) Emission Totals (thousands tons/year) for All Sectors Combined for the NHTSA 2030 Modeling Analyses and Alternatives

	No Action			Alternative 2			Alternative 3			Alternative 4		
Pollutant	DI/A	DI/B	CI	DI/A	DI/B	CI	DI/A	DI/B	CI	DI/A	DI/B	CI
VOCs	11,690	11,683	11,690	11,654	11,651	11,651	11,620	11,618	11,618	11,558	11,550	11,550
NO_x	9,059	9,056	9,059	9,046	9,044	9,044	9,044	9,045	9,045	9,033	9,039	9,039
CO	53,265	53,294	53,265	53,439	53,458	53,458	53,343	53,356	53,356	52,564	52,449	52,449
SO_2	4,897	4,894	4,897	4,881	4,879	4,879	4,876	4,874	4,874	4,889	4,888	4,888
PM_{10}	12,113	12,112	12,113	12,110	12,110	12,110	12,109	12,109	12,109	12,109	12,108	12,108
$PM_{2.5}$	3,546	3,545	3,546	3,544	3,543	3,543	3,542	3,542	3,542	3,539	3,539	3,539
NH_3	4,182	4,182	4,182	4,182	4,182	4,182	4,182	4,182	4,182	4,182	4,182	4,182

Figure E.2.3-1a. Daily VOC Emissions for July 15, 2030: No Action Alternative, Direct and Indirect Impacts, Analysis A

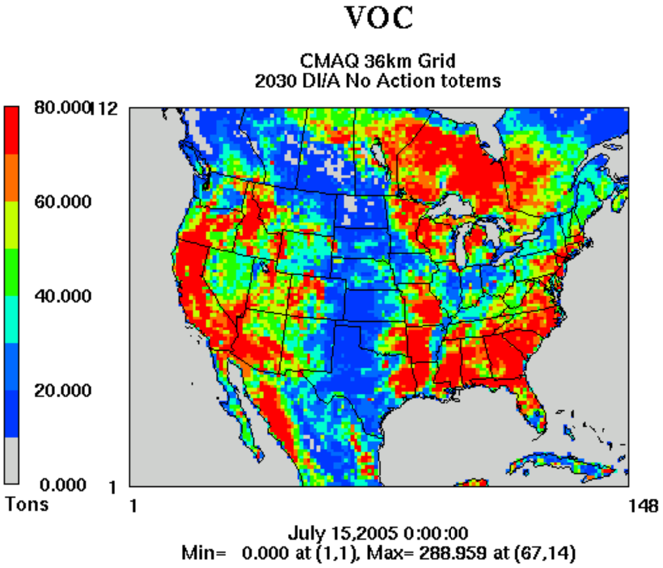


Figure E.2.3-1b. Daily NO_x Emissions for July 15, 2030: No Action Alternative, Direct and Indirect Impacts, Analysis A

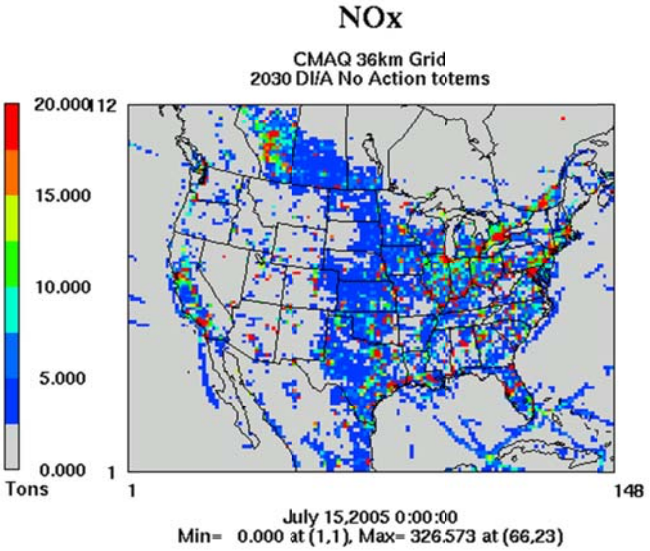


Figure E.2.3-1c. Daily SO_2 Emissions for July 15, 2030: No Action Alternative, Direct and Indirect Impacts, Analysis A

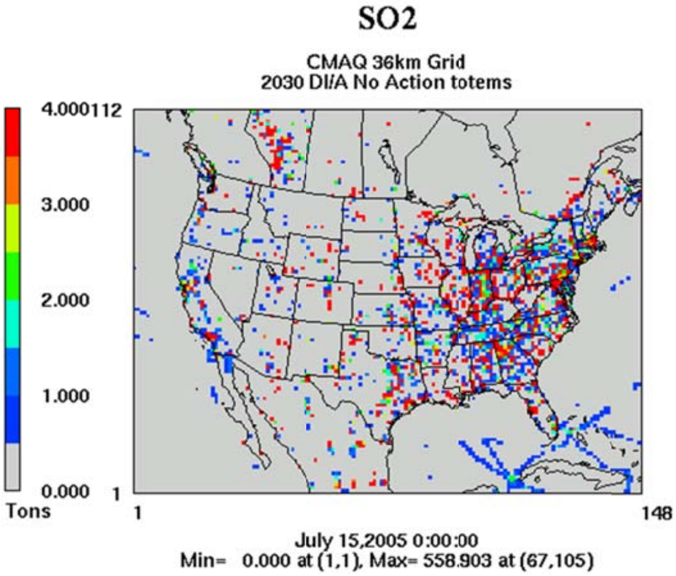
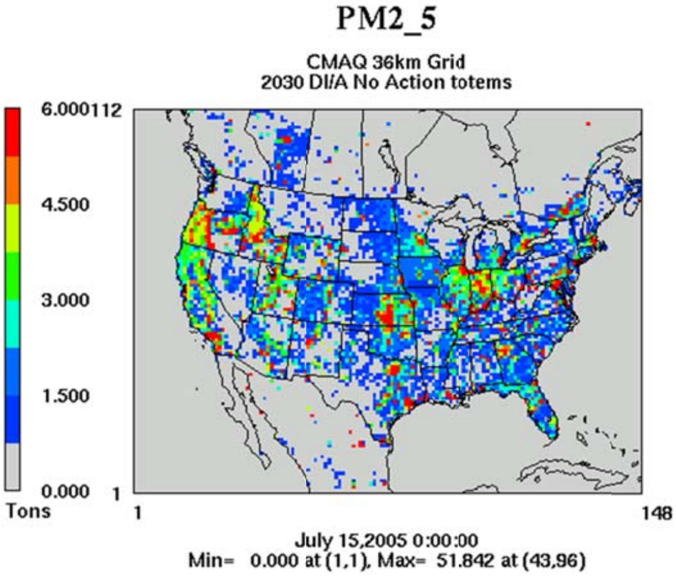


Figure E.2.3-1d. Daily $PM_{2.5}$ Emissions for July 15, 2030: No Action Alternative, Direct and Indirect Impacts, Analysis A



Figures E.2.3-2 (a)-(d) illustrate the spatial distribution of differences (or changes) in emissions for the action alternatives compared to the No Action Alternative. The figures presents difference plots for VOCs, NO_x, SO_2, and $PM_{2.5}$, comparing the emissions under Alternative 4 with the emissions under the No Action Alternative for Analysis A. The difference plots for these two alternatives were selected for presentation because they show the greatest differences between any of the alternatives and the baseline for VOCs, NO_x, and $PM_{2.5}$, and are best suited to illustrate the spatial distribution of the differences (or changes). The difference plots illustrate where the reductions in emissions are expected to occur throughout the 36-kilometer (22.4-mile) resolution modeling domain. The bright green area indicates no change in emissions.

The figures indicate overall reductions in VOC, SO_2, and $PM_{2.5}$ emissions throughout the United States associated with the on-road mobile emission reductions from passenger cars and light trucks and upstream sources. The changes in NO_x emissions reflect the combination of reductions from upstream sources and some increases from on-road mobile sources from the fuel economy rebound effect.

Figure E.2.3-2a. Difference in Daily VOC Emissions for July 15, 2030, for Alternative 4 Compared to the No Action Alternative, Direct and Indirect Impacts, Analysis A

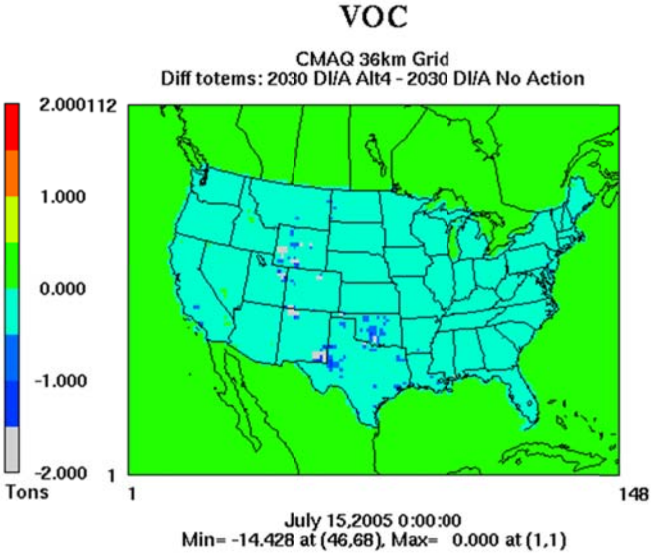


Figure E.2.3-2b. Difference in Daily NO_x Emissions for July 15, 2030, for Alternative 4 Compared to the No Action Alternative, Direct and Indirect Impacts, Analysis A

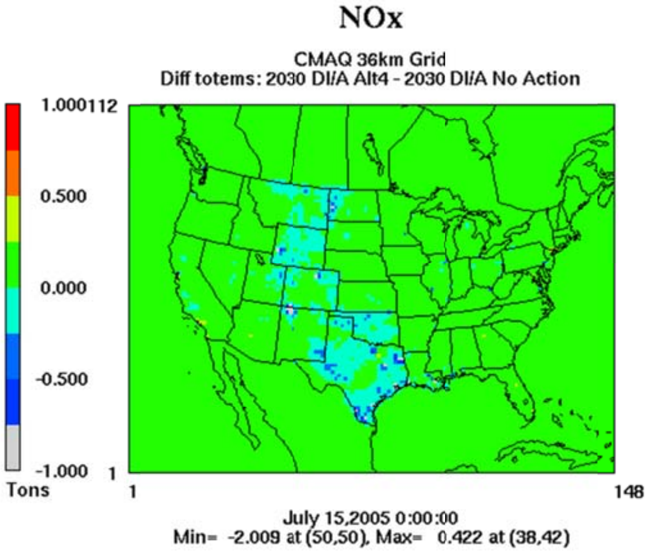


Figure E.2.3-2c. Difference in Daily SO_2 Emissions for July 15, 2030, for Alternative 4 Compared to the No Action Alternative, Direct and Indirect Impacts, Analysis A

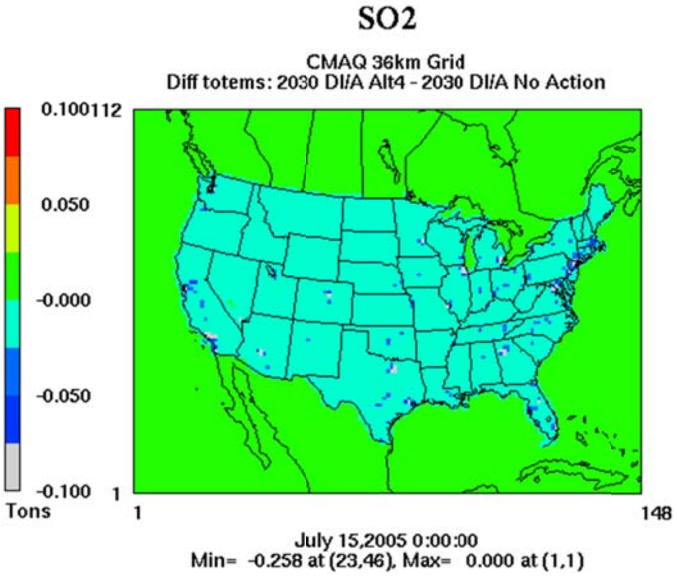
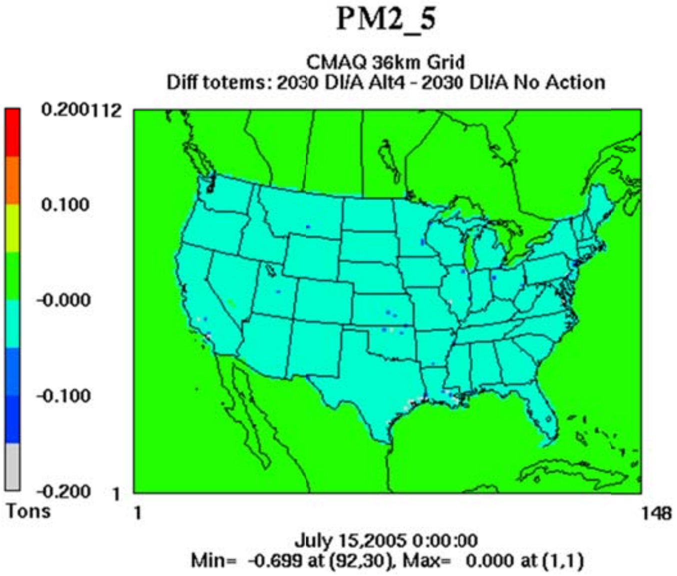


Figure E.2.3-2d. Difference in Daily $PM_{2.5}$ Emissions for July 15, 2030, for Alternative 4 Compared to the No Action Alternative, Direct and Indirect Impacts, Analysis A



Figures E.2.3-3 (a)-(d) present national emission estimates for 2030 by source sector under the No Action Alternative and Alternatives 2, 3 and 4 for Analysis A, Analysis B, and Cumulative Impacts for VOCs, NO_x, SO_2, and $PM_{2.5}$.

Figure E.2.3-3a. National Emission Totals for VOCs in 2030 from Passenger Cars and Light Trucks

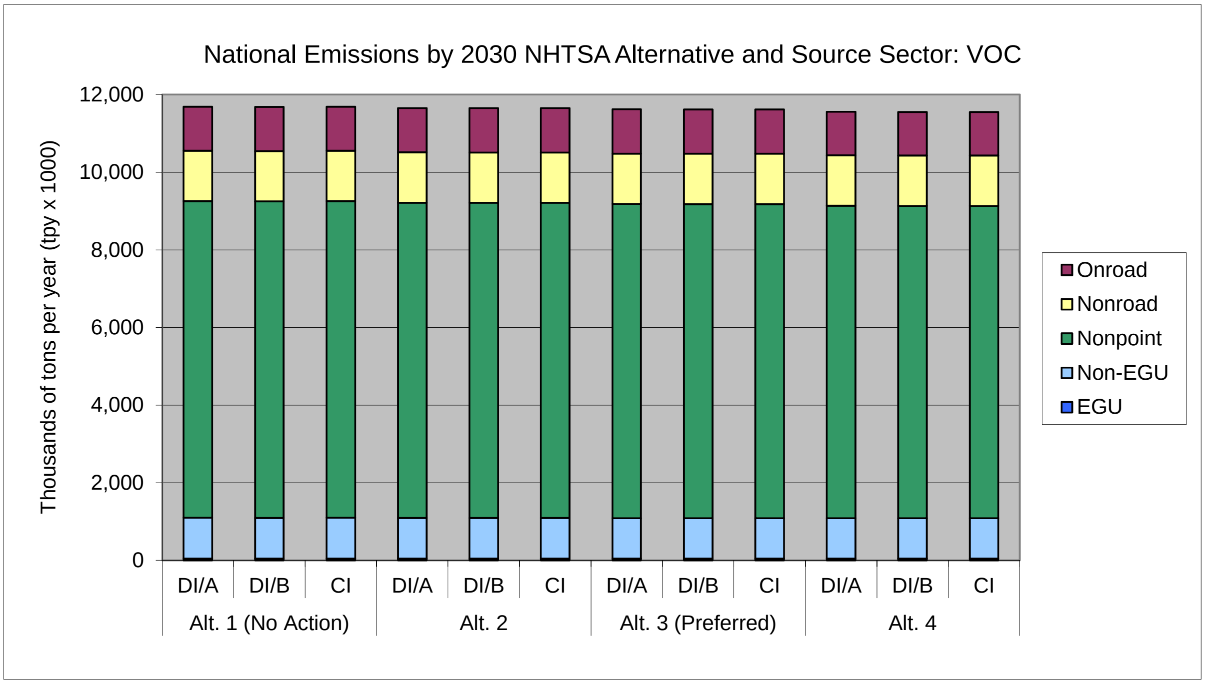


Figure E.2.3-3b. National Emission Totals for NO_x for 2030 under the CAFE Alternatives

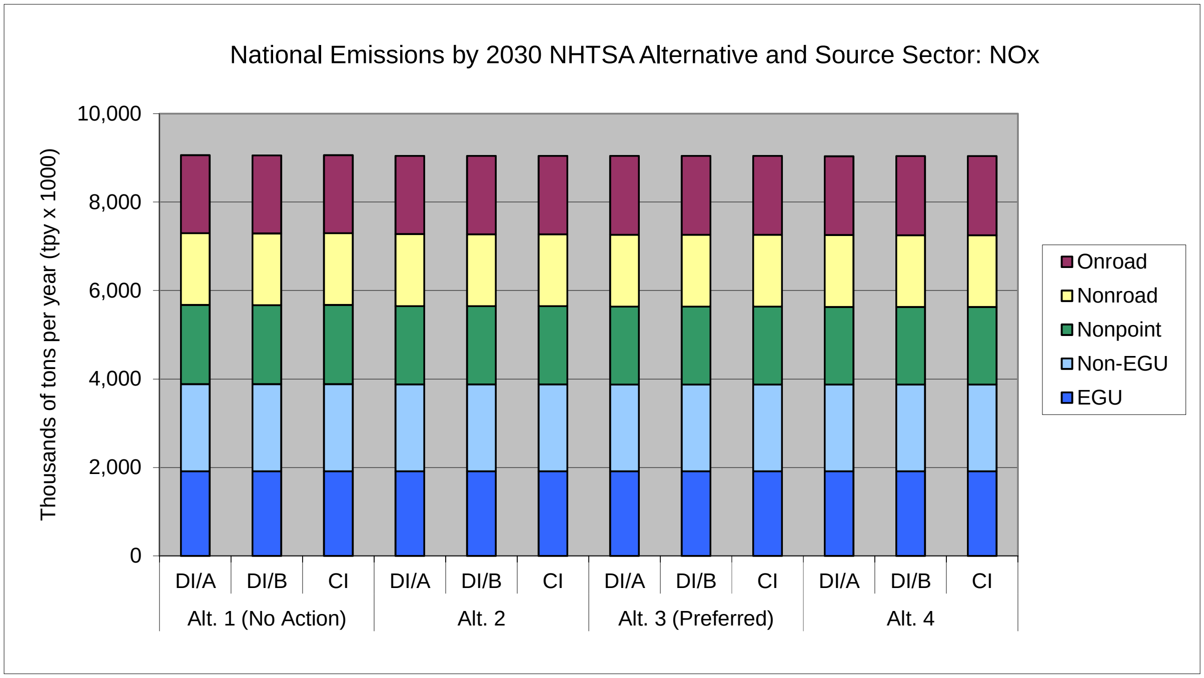


Figure E.2.3-3c. National Emission Totals for SO_2 for 2030 under the CAFE Alternatives

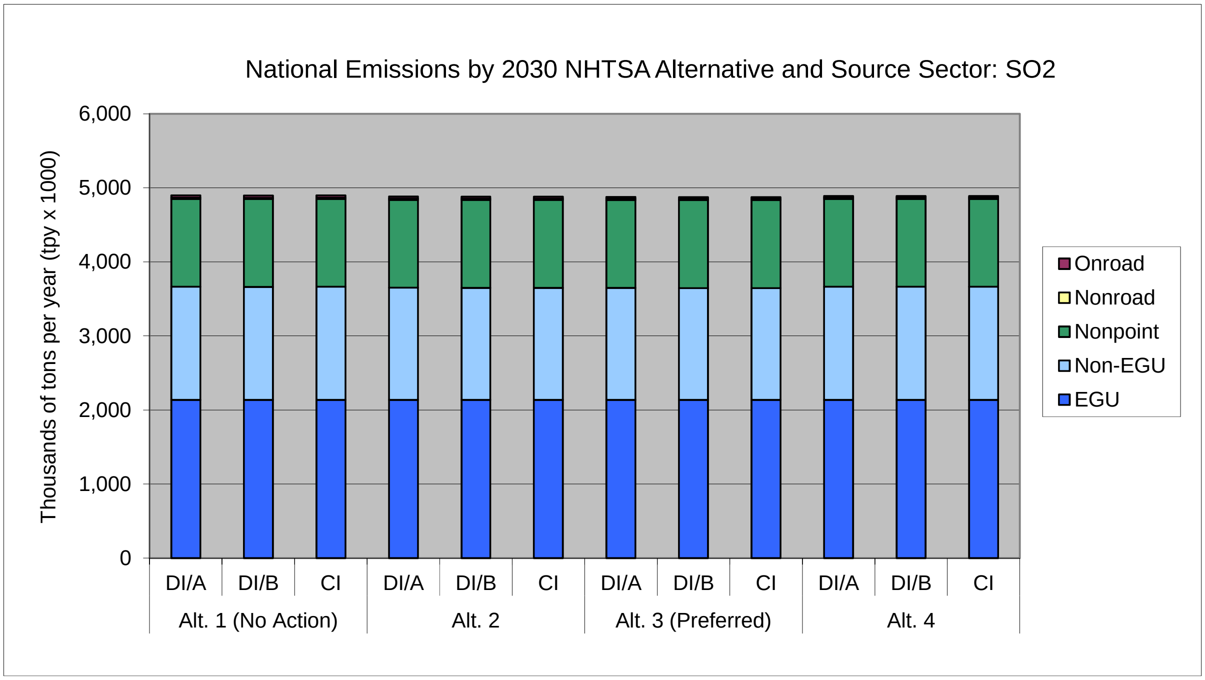
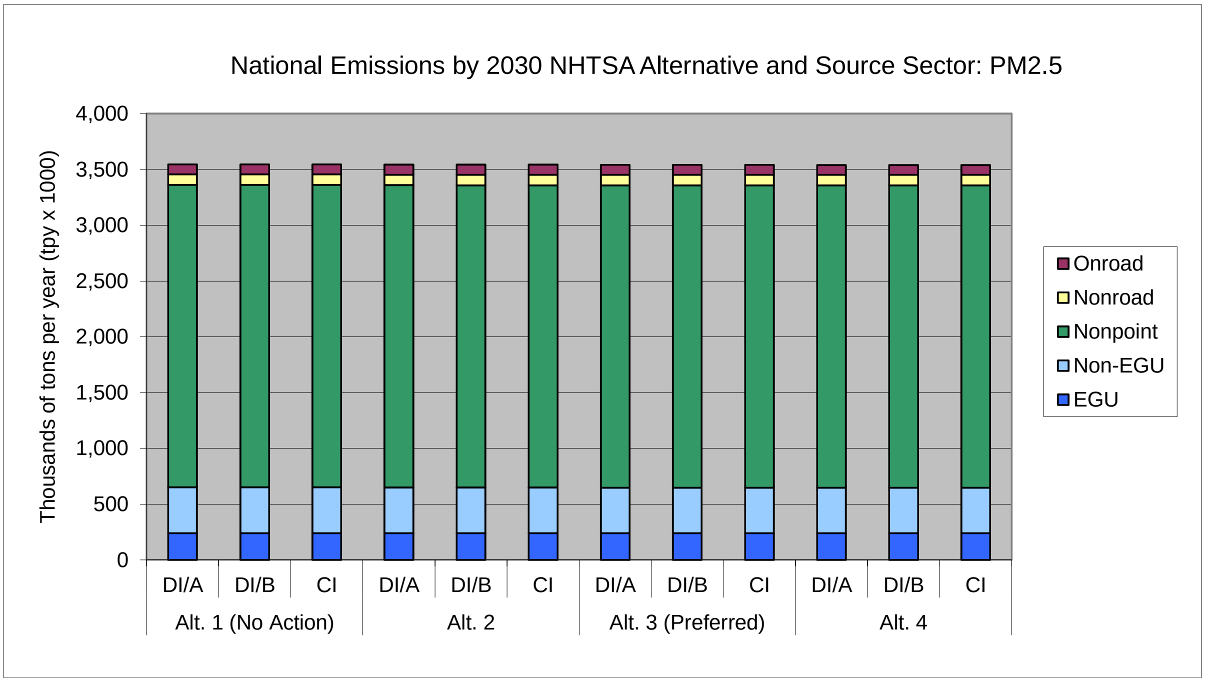


Figure E.2.3-3d. National Emission Totals for $PM_{2.5}$ for 2030 under the CAFE Alternatives



On a national scale, anthropogenic VOC emissions are primarily from area (non-point) sources, and on-road mobile, non-road mobile, and non-EGU sources contribute about equally to total VOCs; NO_x emissions come from all source categories; SO_2 emissions primarily derive from EGU and non-EGU industrial point sources; and $PM_{2.5}$ emissions come primarily from area (non-point) sources. For the action alternatives, the expected changes in emissions for light-duty vehicles are reflected in the on-road mobile source category, while the expected changes in upstream emissions are reflected in the non-point (area) and non-EGU point source categories. Although changes in EGU emissions due to an increase in electric vehicles were included as part of the upstream emissions they were not applied directly to specific EGU sources. These changes account for a small portion of the overall emissions changes on the national level. The estimated decreases in mobile emissions are distributed nationwide, while most of the decreases in upstream emissions are in petroleum development/fuel production states, including Texas, Oklahoma, Louisiana, California, Wyoming, and New Mexico. For all three analyses, a comparison of the No Action Alternative to the action alternatives indicates that national-scale VOC, SO_2, NO_x, and $PM_{2.5}$ emissions are all expected to decrease by less than 1 percent, except for VOC emissions for Alternative 4 under Analysis A, with an expected decrease of about 1.2 percent. On a local scale, depending on source makeup, distribution, and population, the expected decreases in emissions could be larger or smaller than these national averages.

E.3 AIR QUALITY MODELING

This section presents the air quality modeling methods and results. NHTSA used the CMAQ model in this study to simulate the air quality impacts for the Proposed Action and alternatives. The model was applied using a 36-kilometer (22.4-mile) resolution grid at the national scale for an annual simulation period. The CMAQ model requires information on the emissions, meteorology, and land use characteristics of the modeling domain. Information about the emission changes associated with each alternative were incorporated into the model through the emission input files for the modeled year 2030. Because air quality impacts are calculated at the grid-cell level, the CMAQ model can account for regional differences in the relative magnitudes of the changes in emissions due to increased fuel economy, increased vehicle use, and reduced fuel production and distribution potentially resulting from the Proposed Action and alternatives. CMAQ modeling results provide the basis for the health effects and benefits modeling analysis discussed in Section E.4 of this report

E.3.1 Overview of the CMAQ Modeling System

The CMAQ model is a state-of-the-science, regional air quality modeling system that can be used to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere (Byun and Ching 1999). The CMAQ tool was designed to improve the understanding of air quality issues (including the physical and chemical processes that influence air quality) and to support the development of effective emission control strategies on the regional and local scales. The CMAQ model was designed as a “one-atmosphere” model. This concept refers to the ability of the model to dynamically simulate ozone, particulate matter, and other species (such as mercury) in a single simulation. In addition to addressing a variety of pollutants, CMAQ can be applied to a variety of regions (with varying geographical, land use, and emission characteristics) and for a range of space and time scales.

Numerous recent applications of the model, for both research and regulatory air quality planning purposes, have focused on the simulation of ozone and $PM_{2.5}$. NHTSA used the CMAQ model to support the previous analysis of the MYs 2012–2016 CAFE standards (NHTSA 2010) and the analysis of the Medium- and Heavy-Duty Fuel Efficiency Improvement Program (NHTSA 2011b).

The CMAQ model numerically simulates the physical processes that determine the magnitude, temporal variation, and spatial distribution of the concentrations of ozone and particulate species in the atmosphere, and the amount, timing, and distribution of their deposition to Earth’s surface. The simulation processes include advection, dispersion (or turbulent mixing), chemical transformation, cloud processes, and wet and dry deposition. Byon and Ching (1999) describe the CMAQ science algorithms in detail.

This model requires several different types of input files. Gridded, hourly emission inventories characterize the release of anthropogenic, biogenic and, in some cases, geogenic emissions from sources in the modeling domain. The emissions represent low-level and elevated sources and a variety of source categories (including, example.g., point, on-road mobile, non-road mobile, area, and biogenic). The amount and spatial and temporal distribution of each emitted pollutant or precursor species are key determinants of the resulting simulated air quality values.

The CMAQ model also requires hourly, gridded input fields of several meteorological parameters, including wind, temperature, mixing ratio, pressure, solar radiation, fractional cloud cover, cloud depth, and precipitation. Byun and Ching (1999) provide a full list of the meteorological input parameters (1999). The meteorological input fields are typically prepared using a data-assimilating prognostic meteorological model, the output of which is processed for input to the CMAQ model using the Meteorology-Chemistry Interface Processor (MCIP). The prescribed meteorological conditions influence the transport and vertical mixing and resulting distribution of the simulated pollutant concentrations. Certain of the meteorological parameters, such as mixing ratio, can also influence the simulated chemical reaction rates. Rainfall and near-surface meteorological characteristics govern wet and dry deposition, respectively, of the simulated atmospheric constituents.

Initial- and boundary-condition files provide information on pollutant concentrations throughout the domain for the first hour of the first day of the simulation and along the lateral boundaries of the domain for each hour of the simulation. Photolysis rates and other chemistry-related input files supply information needed by the gas-phase and particulate chemistry algorithms.

NHTSA used CMAQ version 4.7 for this study for consistency with EPA's Regulatory Impact Analysis (RIA) modeling. This version of the model supports several options for the gas-phase chemical mechanism, particle treatment, aerosol deposition, and cloud treatment. Compared to previous versions of CMAQ, version 4.7 includes updates to the aqueous chemistry and the advection and diffusion schemes. All simulations conducted as part of this study used the Carbon Bond 2005 chemical mechanism. For particles, NHTSA applied the AERO5 particle treatment, which includes sea salt. In addition, NHTSA used the "inline" point source option, in which point source data are read directly by CMAQ and plume rise is calculated internally based on local meteorological conditions.

E.3.2 CMAQ Application Procedures for the NHTSA Modeling Analysis

This section discusses the application of CMAQ, including the modeling domain, simulation period, input files (with the exception of the emission inventories), and post-processing and quality assurance procedures. (Section E.2 discusses preparation of the emission inventories for the application of CMAQ.)

E.3.2.1 Modeling Domain and Simulation Period

Figure E.1.2-1 shows the modeling domain used for this analysis. The 36-kilometer (22.4-mile) resolution modeling domain includes 148 × 112 grid cells. The tick marks (refer to Figure E.1.2-1) denote the 36-kilometer grid cells. For this domain, NHTSA ran the model for an entire calendar year. The base-year meteorological conditions are for 2005 and the emissions represent 2030. In running the model, the annual simulation period was divided into two parts (January through June, and July through December). Each part of the simulation also included an additional 5 start-up simulation days, which were intended to reduce the influence of uncertainties in the initial conditions on the simulation results.

E.3.2.2 Meteorological and Other Input Files

EPA provided all input files for the application of the CMAQ model, except for certain components of the emission inventories.

EPA prepared the 36-kilometer (22.4-mile) resolution meteorological input files for the base year (2005) using the Pennsylvania State University/National Center for Atmospheric Research Fifth Generation Mesoscale Model (MM5). EPA post-processed the MM5 outputs for input to CMAQ using the MCIP program.

NHTSA used existing initial condition, boundary condition, land-use, and photolysis rate input files for CMAQ modeling for the selected modeling domain and simulation period.

E.3.2.3 Model Performance Evaluation

EPA developed the meteorological fields for 2005 using MM5 (version 3.7.4). EPA applied the model for a 36-kilometer (22.4-mile) resolution grid covering all of the lower 48 states and major portions of Canada and Mexico (EPA 2009). For the performance evaluation, temperature, wind speed, wind direction, and moisture data were obtained from the National Oceanic and Atmospheric Administration's Meteorological Assimilation Data Ingest System, and rainfall data were obtained from the National Weather Service's Climate Prediction Center. The MM5 results for 2005 for the 36-kilometer grid are characterized by very little bias in monthly averaged temperatures throughout the eastern United States, but consistent underprediction of temperature occurs throughout the year in the Rocky Mountain area and the northwestern United States. Except for California, MM5 shows a consistent slight underprediction of monthly averaged wind speeds throughout the United States, with some significant errors in monthly averaged wind direction in California, the Rocky Mountains, and the Pacific Northwest. The patterns predicted by MM5 are fairly consistent with observed data across the United States, but the model tends to overpredict the amount of precipitation in the South and Southeast during summer.

EPA evaluated CMAQ model performance for the 2005 base year as part of the air quality modeling analysis to support the rulemaking for LD GHG emissions standards for MYs 2012–2016 (EPA 2010b). Overall, the performance for the 2005 modeling platform was similar to that for other national- and regional-scale applications, and the model was able to reproduce historical concentrations of ozone and $PM_{2.5}$ with low bias and error results.

In addition, EPA recently used the 2005 MM5 inputs with a similar air quality model (Comprehensive Air Quality Model with Extensions [CAMx]) for the recent air quality transport rule (EPA 2010c) analysis, and NHTSA used the 2005 MM5 input files in this analysis with CMAQ without modification. Overall, EPA found that the performance of CAMx for 2005 showed similar performance statistics for ozone and $PM_{2.5}$ compared to other recent national-scale applications for other years with the CMAQ modeling system. For 2005, the CAMx model tended to overpredict low observed 8-hour daily ozone concentrations and underpredict high observed concentrations. Observed sulfate and ammonium concentrations were underpredicted for the summer months and overpredicted for the other months, while particulate nitrate was underpredicted in the winter months at both rural and urban monitors. Although it is difficult to directly attribute the effects on the performance of the air quality model to known biases in the meteorological inputs, the general underprediction of both high 8-hour ozone and $PM_{2.5}$ components in the summer months in the Eastern United States grid is likely due in part to the MM5 overestimation of rainfall in the South and Southeast during these months.

In summary, given the performance of the MM5, CMAQ, and CAMx modeling systems in replicating the 2005 annual period, the use of the MM5-derived inputs to drive the CMAQ air quality modeling system for the CAFE analysis should provide acceptable estimates of 8-hour ozone and $PM_{2.5}$ concentrations throughout the United States. Based on past performance, simulated concentrations of peak 8-hour ozone and $PM_{2.5}$ species in the summer months in the Eastern United States are likely somewhat underestimated, and could have some effect on concentration estimates derived for each analysis and each alternative. However, the use of the differences between the future baseline and each of the analyses, rather than absolute concentrations, tends to mitigate the influence of potential bias in the simulated base year concentration fields derived with the MM5/CMAQ modeling system.

E.3.2.4 Post-processing and Quality Assurance Procedures

Quality assurance of the CMAQ runs included the following steps:

- NHTSA routinely checked scripts to ensure that the correct input files and output file names were used. They checked and reconciled any error messages CMAQ generated.
- NHTSA prepared plots of ozone, $PM_{2.5}$, and selected particulate species for each month and each simulation. For ozone, NHTSA plotted concentrations for the 15th day of each month; for $PM_{2.5}$, they plotted monthly averages. These were examined and compared with the results for other runs. NHTSA checked the concentration patterns and values for reasonableness, and compared the results for each month and each alternative to ensure that differences in the CMAQ results were consistent with the emissions changes.

Following these actions to ensure the quality of the modeling results, NHTSA post-processed the CMAQ results for input to the health impacts and benefits modeling, as discussed in Section E.4 of this report.

E.3.3 CMAQ Modeling Results

The following sections first present results for the No Action Alternative for Analysis A, Analysis B, and Cumulative Impacts. The sections follow with a description of the differences between each action alternative and the No Action Alternative for that analysis. The modeling results for ozone and $PM_{2.5}$ were used to calculate health effects and monetized health-related benefits provided in Section E.4 of this report.

E.3.3.1 Direct and Indirect Impacts, Analysis A

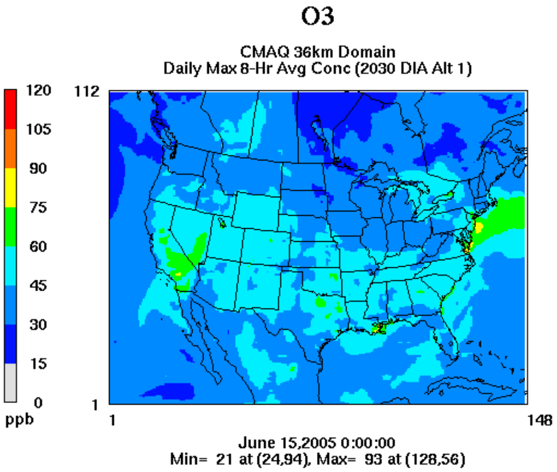
This section presents and compares CMAQ results for Analysis A. The results for ozone are presented first, followed by the results for $PM_{2.5}$.

E.3.3.1.1 Ozone

Figure E.3.3.1-1 shows simulated daily maximum 8-hour ozone concentrations (parts per billion [ppb]) for the 15th of June for the Analysis A No Action Alternative. NHTSA selected this day as an example ozone-season day for display of the ozone concentrations (for all simulations), primarily because of relatively higher ozone concentrations on this day compared to other days comprising the simulation period, but also because the meteorological conditions and resulting concentration patterns are typical of the ozone season. The date and time given on this and all subsequent figures refer to the meteorological base year (2005) and start hour for the selected day or averaging period. The minimum and maximum values for any location in the domain are also provided, along with their grid-cell (x,y) locations.

Figure E.3.3.1-1 indicates that daily maximum ozone concentrations for this day are generally less than 75 ppb (the current 8-hour ozone National Ambient Air Quality Standards [NAAQS] level). There are a few areas with higher ozone concentrations, especially in California and Nevada, in the Mid-south, and along the Northeast corridor. This example is representative of the ozone results for all months and shows that most areas would be in attainment of the current 8-hour ozone standard by 2030.

Figure E.3.3.1-1. Simulated Daily Maximum 8-hour Ozone Concentration (ppb) for June 15, 2030: No Action Alternative, Direct and Indirect Impacts, Analysis A

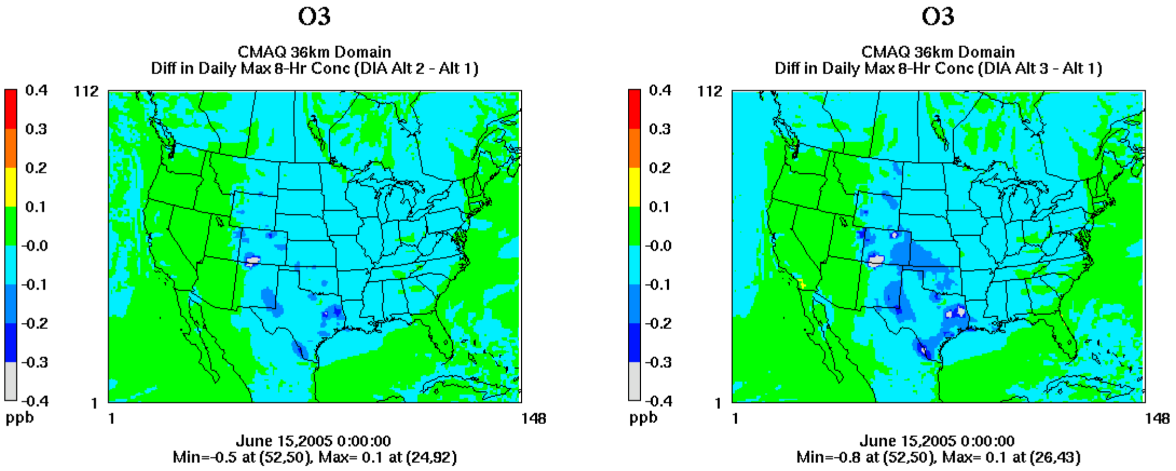


From a meteorological perspective, the observed ozone concentration patterns on June 15, 2005, were affected by typical early summer, large-scale weather features situated over the continental United States, with an upper-level ridge centered over the west-central portion of the country, stretching from the Dakotas to Texas, and an upper-level trough situated on a line from Ontario to the Ohio Valley. The upper-level ridge and associated surface high-pressure system resulted in clear skies, no precipitation, light winds, and normal to above-normal temperatures in the western United States. The trough and associated low-pressure system and weak cold front that stretched from the New England states toward Southeast states resulted in normal seasonal high temperatures and areas of light precipitation in the Upper Midwest, Ohio Valley, and New England states, while the southern tier of states exhibited above-normal high temperatures in the mid to upper 90s, mostly clear skies, and little precipitation. The winds aloft over areas of the western United States affected by the ridge were fairly light, while the winds over the Great Lakes states and upper Ohio Valley areas affected by the trough were moderate.

Figures 3.3.1-2 (a)-(c) illustrate the simulated differences in daily maximum 8-hour ozone between each action alternative and the No Action Alternative for Analysis A (Alternative 2 minus No Action, Alternative 3 minus No Action, and Alternative 4 minus No Action). Again the results for June 15th are displayed. The small increases and decreases in ozone concentration are characteristic of all simulation days.

Although the differences in ozone concentration are projected to be small, especially compared to the current ozone standard (75 ppb), the location, extent, and magnitude of the changes (primarily decreases) in ozone concentration are consistent with the emission changes. The greatest reduction in emissions occurs for the upstream emissions and the greatest reduction in ozone occurs in regions where oil and gas production is known to occur. The differences in ozone concentration between each alternative and the No Action Alternative (decreases in concentration) are smallest under Alternative 2, and slightly larger under Alternatives 3 and 4. The maximum decrease in ozone concentrations for any given grid cell is 0.5 ppb under Alternative 2, 0.8 ppb under Alternative 3, and 1 ppb under Alternative 4. The maximum increase in ozone concentration is 0.1 ppb under all three alternatives.

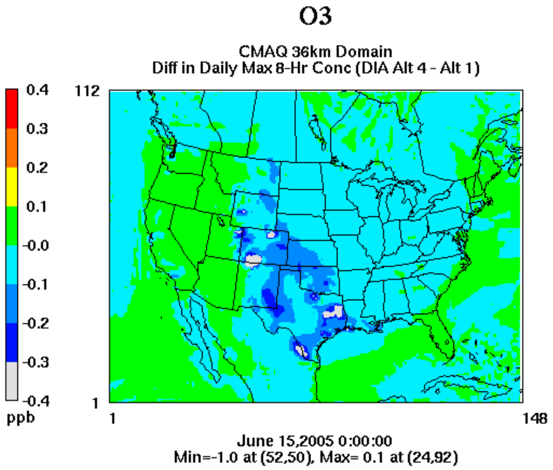
Figure E.3.3.1-2. Difference in Simulated Daily Maximum 8-hour Ozone Concentration (ppb) for June 15, 2030: Direct and Indirect Impacts under Alternatives 2, 3, and 4 Compared to the No Action Alternative, Analysis A



(a) Alternative 2

(b) Alternative 3

(c) Alternative 4



The response of the CMAQ model to the changes in emissions is complicated due to a mix of increases and decreases in the precursor emissions for the alternatives. The key precursor pollutants for ozone are VOCs and NO_x. Upstream emissions of both VOCs and NO_x are lower under all alternatives compared to the No Action Alternative. The amount by which the emissions are reduced is greatest under Alternative 4. This is reflected in the modeling results as a decrease in ozone concentrations over Texas and other oil- and gas-producing states. Tailpipe emissions, especially for NO_x, are generally slightly higher under the action alternatives compared to the No Action Alternative (reflecting the VMT rebound effect). This overall increase in tailpipe emissions could account for the slight increase in ozone concentrations in the western United States and near several major cities in the eastern part of the United States. The increases and decreases vary among the alternatives and between passenger cars and light-duty trucks.

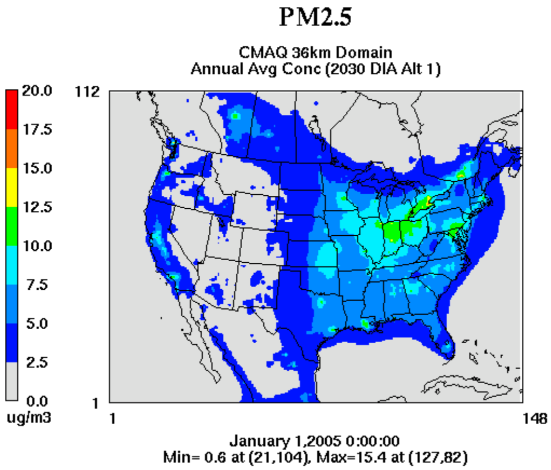
The response of the model to changes in emissions is also influenced by the complex photochemistry represented by the model. Under certain conditions (usually characterized by a high VOC-to-NO_x ratio), decreases in NO_x emissions can lead to increases in ozone. This is typically expected to occur in urban areas.

Therefore, as evidenced by the concentration difference patterns, the response of the model to the changes in emissions is quite complex for ozone. It varies from region to region, and is influenced by the amount and spatial distribution of the emission changes, and the relative changes in emissions for the different pollutant species (VOCs versus NO_x).

E.3.3.1.2 $PM_{2.5}$

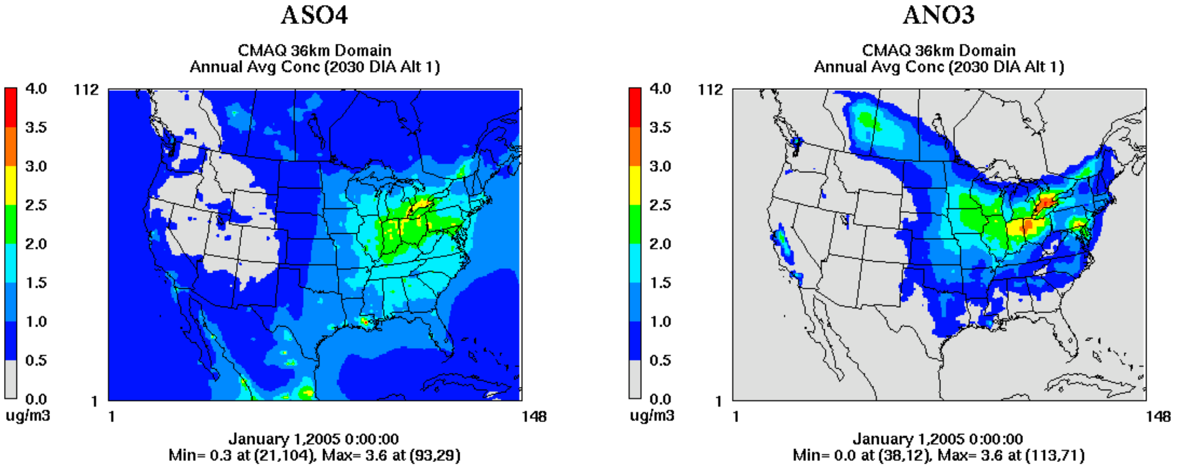
Figure E.3.3.1-3 displays simulated annual average $PM_{2.5}$ concentrations (micrograms per cubic meter [μgm^3]) under the No Action Alternative for Analysis A. This plot indicates areas of higher $PM_{2.5}$ in the eastern United States and in California, with an area of relative high concentration over several Midwestern states. Except for an isolated grid cell or two, no area is characterized by an annual average concentration greater than the current annual NAAQS of 15 μgm^3. The date and time given on the figures refer to the meteorological base year and start hour for the selected day or averaging period. The minimum and maximum values for any location in the domain are also provided, along with their grid cell (x,y) locations.

Figure E.3.3.1-3. Simulated Annual Average $PM_{2.5}$ Concentration (μgm^3) for 2030: No Action Alternative, Direct and Indirect Impacts, Analysis A



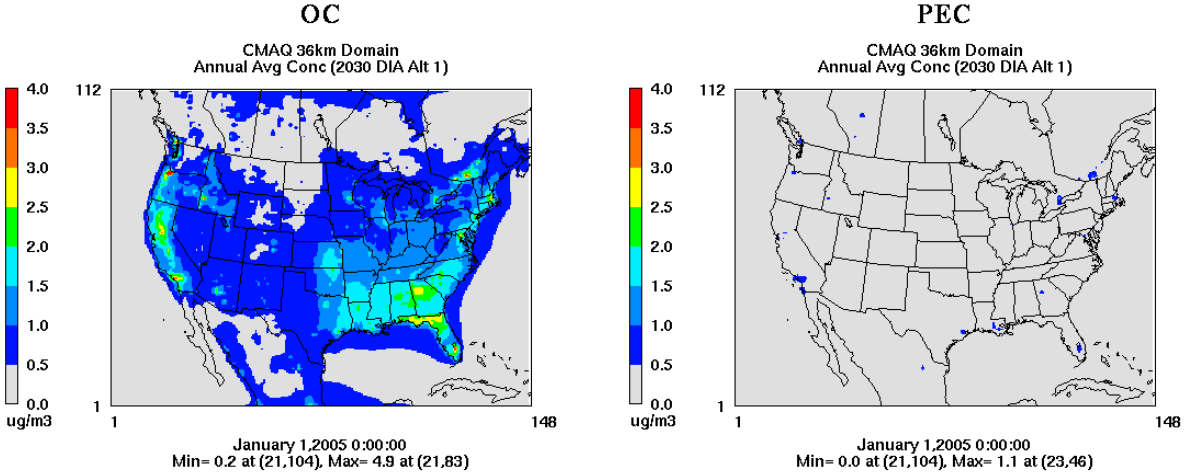
$PM_{2.5}$ is composed of various components, including sulfate, nitrate, organic carbon, and elemental carbon. Precursor emissions for all four component species would be affected by the Proposed Action, from both tailpipe and upstream emissions. Figures 3.3.1-4 (a)-(d) plot the simulated concentrations of these component species.

Figure E.3.3.1-4. Simulated Annual Average $PM_{2.5}$ Species Concentration (µgm^3) for 2030: No Action Alternative, Direct and Indirect Impacts, Analysis A



(a) Sulfate

(b) Nitrate

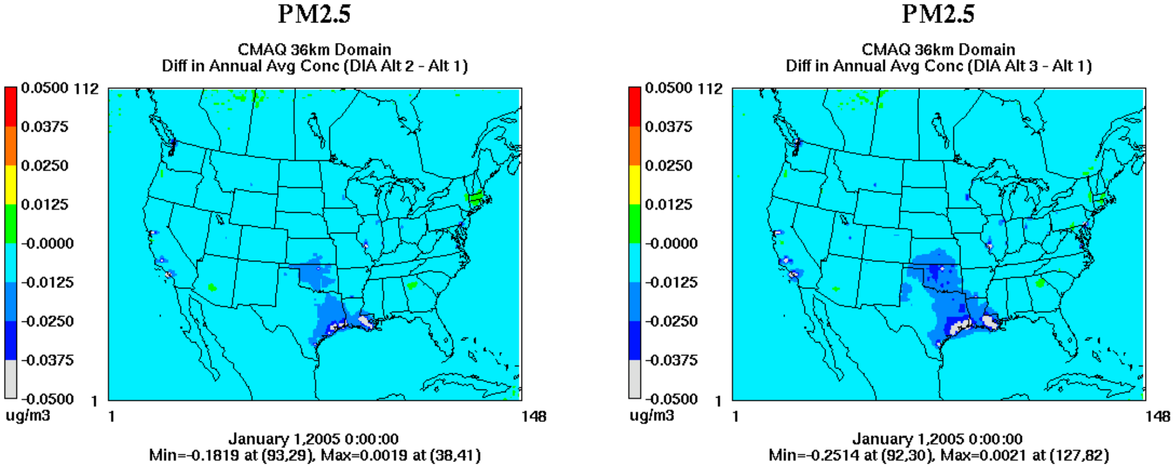


(c) Organic Carbon

(d) Elemental Carbon

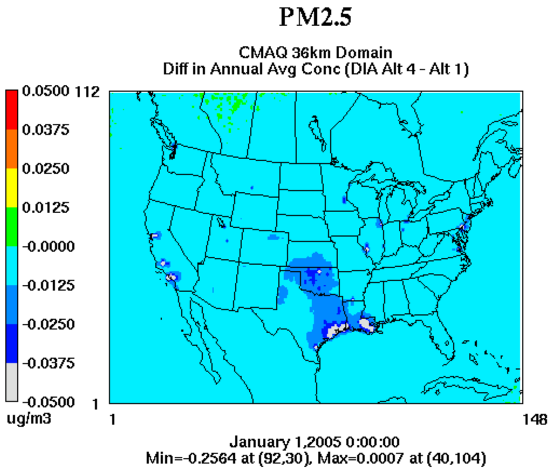
Figures 3.3.1-5 (a)-(c) display the difference in simulated annual average $PM_{2.5}$ concentration (µgm^3) for each alternative compared to the No Action Alternative for Analysis A (Alternative 2 minus No Action, Alternative 3 minus No Action, and Alternative 4 minus No Action). The differences are characterized predominantly by decreases in $PM_{2.5}$ concentration.

Figure E.3.3.1-5. Difference in Simulated Annual Average $PM_{2.5}$ Concentration (ppb): Direct and Indirect Impacts under Alternatives 2, 3, and 4 Compared to the No Action Alternative Under Analysis A



(a) Alternative 2 *(b) Alternative 3*

(c) Alternative 4



The greatest decreases in $PM_{2.5}$ occur in areas associated with oil and gas production and refining, such as the Gulf Coast (near Houston, Texas, and Baton Rouge, Louisiana) and California. The key precursor pollutants for secondary $PM_{2.5}$ are SO_2, NO_x, and VOCs. Upstream emissions for these species are lower under all action alternatives compared to the No Action Alternative, and this is reflected in the modeling results as a decrease in $PM_{2.5}$ concentration over Texas and other oil- and gas-producing states. Thus, the model response is consistent with the reduction in upstream emissions expected to occur under the Proposed Action. The differences in $PM_{2.5}$ concentration between each alternative and the No Action Alternative (decreases in concentration) are smallest under Alternative 2, and slightly larger under Alternatives 3 and 4. The maximum decrease in $PM_{2.5}$ concentration for any given grid cell is 0.18 $\mu g/m^3$ under Alternative 2, 0.25 $\mu g/m^3$ under Alternative 3, and 0.26 $\mu g/m^3$ under Alternative 4. The maximum increase in $PM_{2.5}$ concentration is less than 0.01 $\mu g/m^3$ under all three alternatives.

Again, the response of the CMAQ model to the changes in emissions is complicated due to a mix of increases and decreases in the precursor emissions for the alternatives. The difference plots for $PM_{2.5}$ indicate that the reductions in this region are greatest under Alternative 3 (decreases in $PM_{2.5}$ greater than 0.025 µg/m^3 [dark blue] cover a larger area). An important precursor of secondary $PM_{2.5}$ (especially in the southeastern United States) is SO_2, and the SO_2 emissions reductions associated with the upstream category are greatest under Alternative 3. Therefore, the difference plots are consistent with the emissions changes and show a greater reduction in $PM_{2.5}$ concentration in this region. In contrast, reductions in tailpipe emissions of SO_2, VOCs, and primary $PM_{2.5}$ are greatest under Alternative 4, and these contribute to reductions in $PM_{2.5}$ in other regions (mostly urban areas) under Alternative 4.

Therefore, as evidenced by the concentration difference patterns, the response of the model to the changes in emissions is also quite complex for $PM_{2.5}$, especially when comparing the alternatives. The response varies from region to region, and is influenced by the amount and spatial distribution of the emission changes and the relative changes in emissions for the different pollutant species. Because the emission changes for the upstream and tailpipe components do not vary uniformly from one alternative to another, the response also varies among the alternatives.

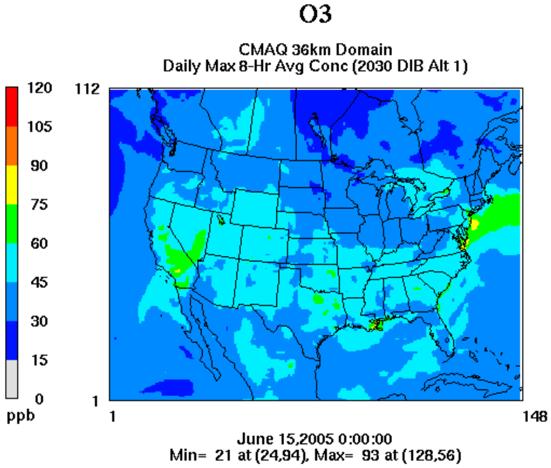
E.3.3.2 Direct and Indirect Impacts, Analysis B

This section presents and compares CMAQ results for Analysis B. The results for ozone are presented first, followed by the results for $PM_{2.5}$.

E.3.3.2.1 Ozone

Figure E.3.3.2-1 displays simulated daily maximum 8-hour ozone concentrations (ppb) for the 15th of June under the No Action Alternative for Analysis B. The simulated ozone concentrations are very similar to those for Analysis A, reflecting only small differences in emissions between the analyses for 2030.

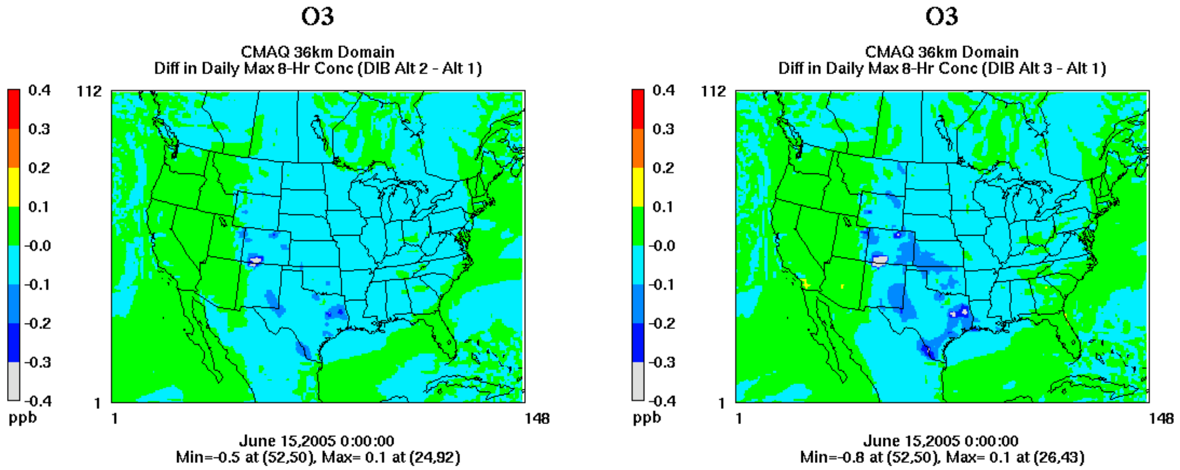
Figure E.3.3.2-1. Simulated Daily Maximum 8-hour Ozone Concentration (ppb) for June 15, 2030: No Action Alternative, Direct and Indirect Impacts, Analysis B



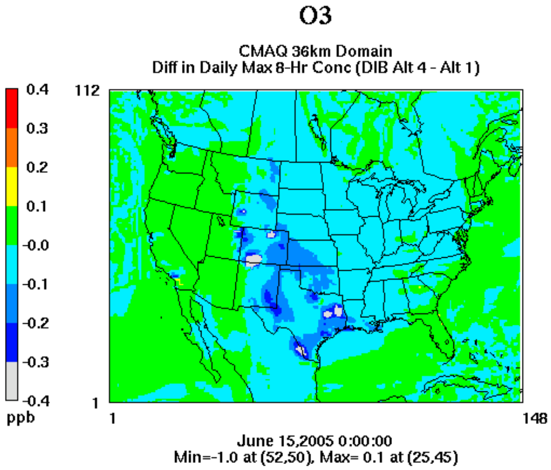
Figures E.3.3.2-2 (a)-(c) illustrate the simulated differences in daily maximum 8-hour ozone between each action alternative and the No Action Alternative for Analysis B (Alternative 2 minus No Action, Alternative 3 minus No Action, and Alternative 4 minus No Action). Again the results for June 15th are displayed. The small increases and decreases in ozone concentration are characteristic of all simulation days.

Figure E.3.3.2-2. Difference in Simulated Daily Maximum 8-hour Ozone Concentration (ppb) for June 15, 2030: Direct and Indirect Impacts under Alternatives 2, 3, and 4 Compared to the No Action Alternative Under Analysis B

(a) Alternative 2 *(b) Alternative 3*



(c) Alternative 4

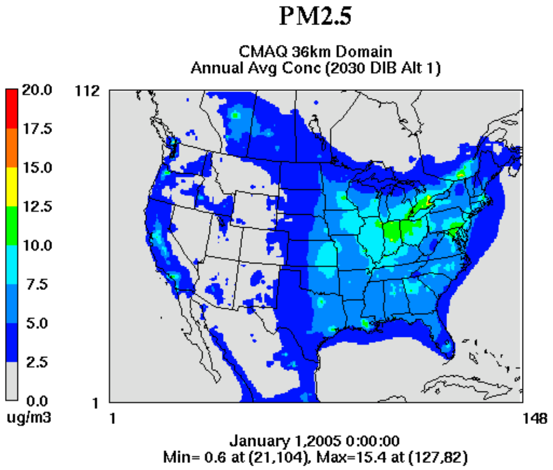


Similar to Analysis A, the differences in simulated ozone concentration are small. The differences in ozone concentration between each alternative and the No Action Alternative (decreases in concentration) are smallest under Alternative 2, and slightly larger under Alternatives 3 and 4. The maximum decrease in ozone concentration for any given grid cell is 0.5 ppb under Alternative 2, 0.8 ppb under Alternative 3, and 1 ppb under Alternative 4. The maximum increase in ozone concentration is 0.1 ppb under all three alternatives.

E.3.3.2.2 $PM_{2.5}$

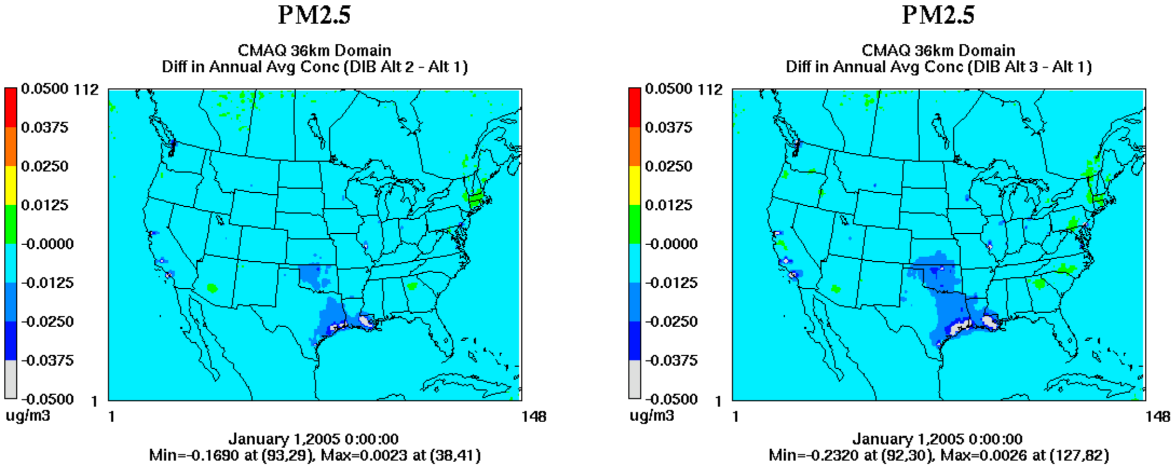
Figure E.3.3.2-3 displays simulated annual average $PM_{2.5}$ concentration (μgm^3) under the No Action Alternative for Analysis B. The simulated $PM_{2.5}$ concentrations are very similar to those for Analysis A. Simulated concentrations of the component species under the No Action Alternative for Analysis B (not shown) are also very similar to those for Analysis A.

Figure E.3.3.2-3. Simulated Annual Average $PM_{2.5}$ Concentration (µgm^3) for 2030: No Action Alternative, Direct and Indirect Impacts, Analysis B



Figures E.3.3.2-4 (a)-(c) display the difference in simulated annual average $PM_{2.5}$ concentration (μgm^3) under each action alternative compared to the No Action Alternative for Analysis B (Alternative 2 minus No Action, Alternative 3 minus No Action, and Alternative 4 minus No Action).

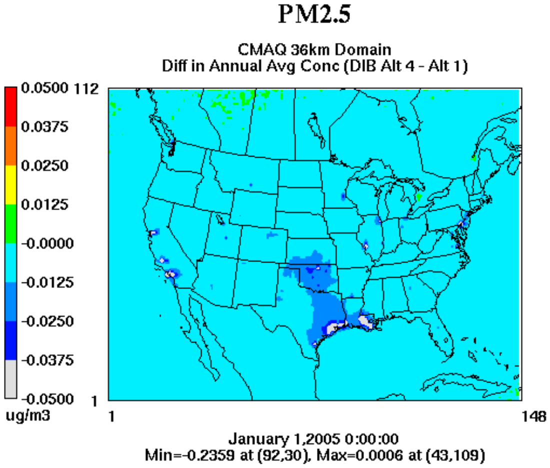
Figure E.3.3.2-4. Difference in Simulated Annual Average $PM_{2.5}$ Concentration (ppb): Direct and Indirect Impacts under Alternatives 2, 3, and 4 Compared to the No Action Alternative Under Analysis B



(a) Alternative 2

(b) Alternative 3

(c) Alternative 4



As for Analysis A, the simulated differences for Analysis B are characterized predominantly by decreases in $PM_{2.5}$ concentration. The differences in concentration between each action alternative and the No Action Alternative (decreases in concentration) are smallest under Alternative 2 and slightly larger under Alternatives 3 and 4. The maximum simulated decrease in annual average $PM_{2.5}$ for any grid cell in the domain is approximately 0.17 µg/m^3 under Alternative 2, 0.23 under Alternative 3, and 0.24 under Alternative 4.

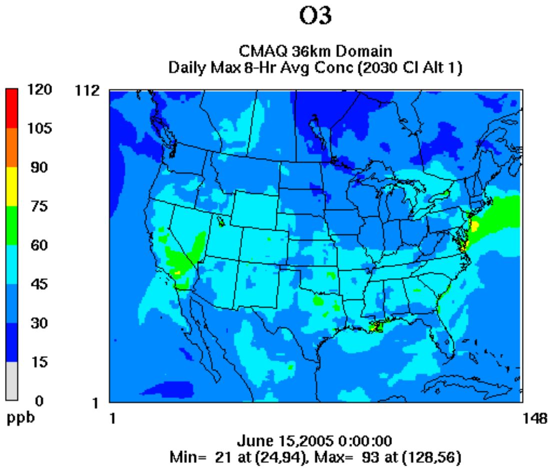
E.3.3.3 Cumulative Impacts

This section presents and compares results for Cumulative Impacts. The results for ozone are presented first, followed by the results for $PM_{2.5}$.

E.3.3.3.1 Ozone

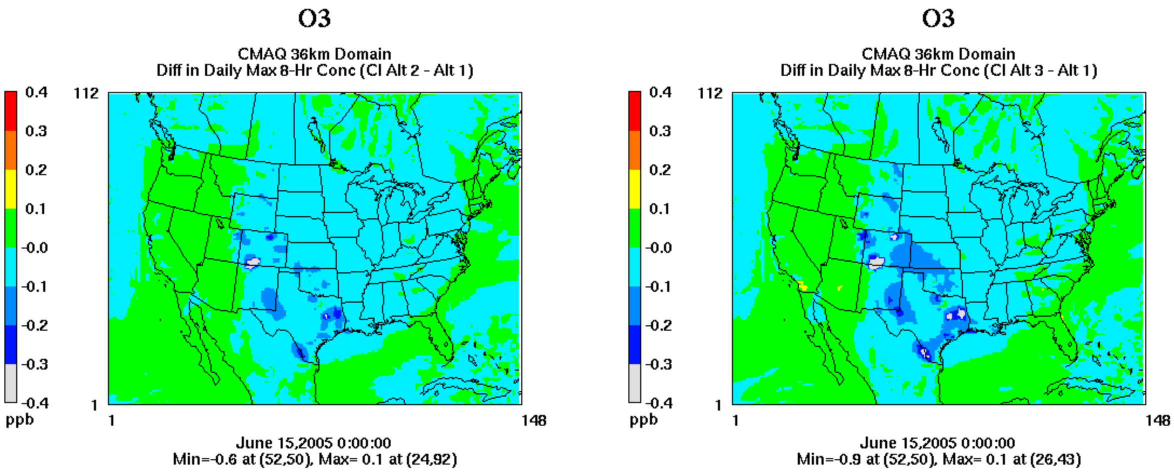
Figure E.3.3.3-1 displays simulated daily maximum 8-hour ozone concentration (ppb) for the 15th of June under the No Action Alternative for Cumulative Impacts. The simulated ozone concentrations are identical to those for Analysis A.

Figure E.3.3.3-1. Simulated Daily Maximum 8-hour Ozone Concentration (ppb) for June 15, 2030: No Action Alternative, Cumulative Impacts



Figures E.3.3.3-2 (a)-(c) illustrate the simulated differences in daily maximum 8-hour ozone between each action alternative and the No Action Alternative for Cumulative Impacts (Alternative 2 minus No Action, Alternative 3 minus No Action, and Alternative 4 minus No Action). Again the results for June 15th are displayed. The small increases and decreases in ozone concentration are characteristic of all simulation days.

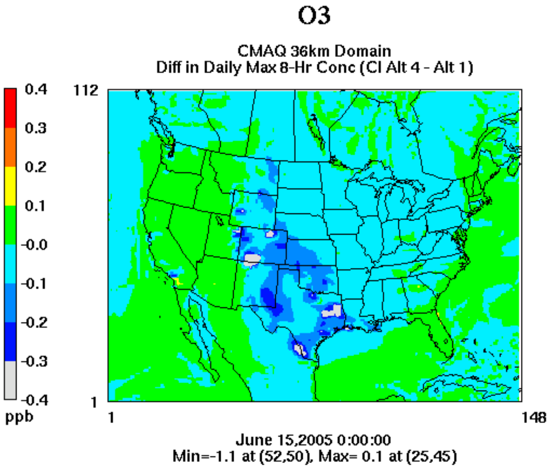
Figure E.3.3.3-2. Difference in Simulated Daily Maximum 8-hour Ozone Concentration (ppb) for June 15, 2030: Cumulative Impacts under Alternatives 2, 3, and 4 Compared to the No Action Alternative



(a) Alternative 2

(b) Alternative 3

(c) Alternative 4

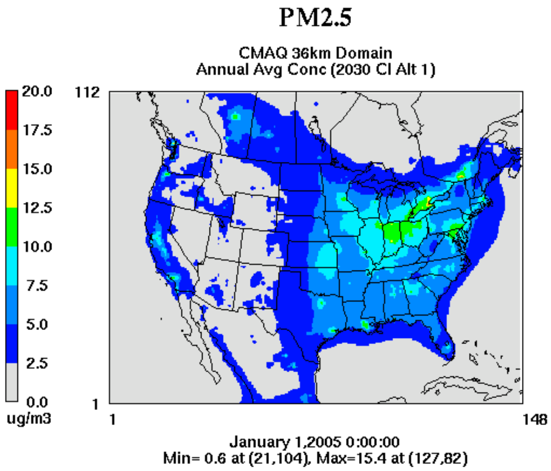


The differences in simulated ozone concentration are slightly larger than for Analysis A and Analysis B. The maximum decrease in ozone concentration for any given grid cell is 0.6 ppb under Alternative 2, 0.9 ppb under Alternative 3, and 1.1 ppb under Alternative 4. The maximum increase in ozone concentration is 0.1 ppb under all three alternatives.

E.3.3.3.2 PM$_{2.5}$

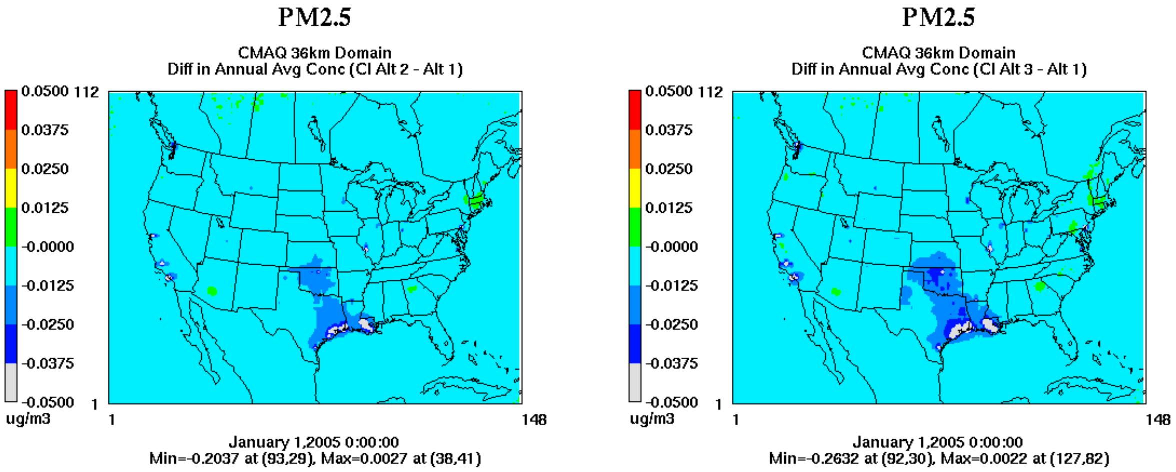
Figure E.3.3.3-3 displays simulated annual average PM$_{2.5}$ concentration (µgm^{3}) under the No Action Alternative for Cumulative Impacts. The simulated PM$_{2.5}$ concentrations are identical to those for Analysis A.

Figure E.3.3.3-3. Simulated Annual Average PM$_{2.5}$ Concentration (µgm^{3}) for 2030: No Action Alternative, Cumulative Impacts

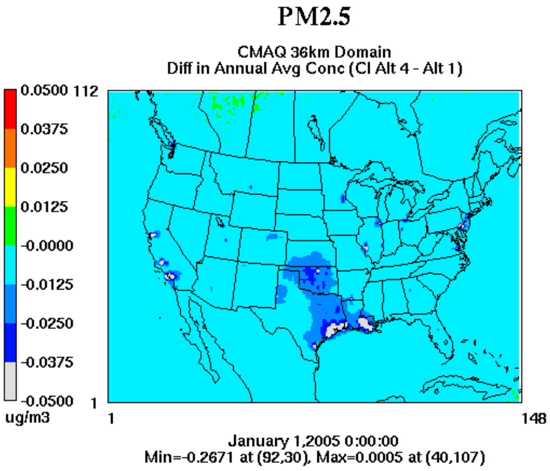


Figures E.3.3.3-4 (a)-(c) display the difference in simulated annual average $PM_{2.5}$ concentration (μgm^3) for each action alternative compared to the No Action Alternative for Cumulative Impacts (Alternative 2 minus No Action, Alternative 3 minus No Action, and Alternative 4 minus No Action).

Figure E.3.3.3-4. Difference in Simulated Annual Average $PM_{2.5}$ Concentration (ppb): Cumulative Impacts under Alternatives 2, 3, and 4 Compared to the No Action Alternative


(a) Alternative 2 *(b) Alternative 3*

(c) Alternative 4



As for Analysis A and Analysis B, the simulated differences for Cumulative Impacts are characterized predominantly by decreases in $PM_{2.5}$ concentration. The differences in concentration between each action alternative and the No Action Alternative (decreases in concentration) are slightly larger than for Analysis A and Analysis B. The maximum simulated decrease in annual average $PM_{2.5}$ for any grid cell in the domain is approximately 0.2 μgm^3 under Alternative 2, 0.26 under Alternative 3, and 0.27 under Alternative 4.

E.3.3.4 Discussion of Attributes, Limitations and Uncertainties

The CMAQ air quality modeling system provides a reliable platform for evaluating the expected responses to changes in precursor emissions at the national and regional scales. The detailed, quantitative modeling results provide an excellent basis for comparing the effects of the alternatives and provide the requisite input for the health effects modeling.

CMAQ can account for differences in emissions and other factors that affect air quality and the resulting health impacts at any given location, such as meteorology, topography, land use, and atmospheric chemistry processes. Accordingly, CMAQ can simulate regional differences in the response of the model to the emission changes. This is important because different regions of the country could experience either a net increase or a net decrease in emissions due to the proposed standards, depending on the relative magnitudes of the changes in emissions due to increased fuel economy, increased vehicle use, and reduced fuel production and distribution. Regional differences in the response of the model to changes in emissions are also important in the calculation of health effects, because the air quality changes are matched to gridded population estimates.

All air quality modeling exercises are affected by inherent uncertainties that derive from model formulation (including numerical approximations and the parameterization of physical and chemical processes) and inaccuracies in the input fields (including the meteorological inputs and emission inventory estimates). The following paragraphs discuss a number of key limitations and uncertainties, both general and specific to this analysis.

One limitation of this application of CMAQ is the use of 36-kilometer (22.4-mile) horizontal grid resolution. Although this grid resolution is consistent with current EPA modeling guidance and practice for annual and seasonal modeling for $PM_{2.5}$, it is coarser than that typically used for ozone. This grid resolution might not be sufficiently detailed to resolve certain sub-grid scale processes (e.g., emissions, meteorology, and atmospheric chemistry) in portions of the modeling domain, and this could introduce biases or uncertainties into the simulated concentration fields. Use of 36-kilometer grid resolution might limit the response of the model to small changes in precursor emissions, especially for ozone.

Pollutants such as ozone and $PM_{2.5}$ are secondary pollutants formed through atmospheric chemical processes. There are many different reaction pathways and there are uncertainties associated with each pathway as represented in the CMAQ model.

The emission estimates for on-road motor vehicles and the affected upstream emission sources used in this analysis are total emissions for all states and Washington, DC. These were spatially allocated to each state and county using VMT and other activity information. These emissions assume that emission rates for vehicles are the same across the United States. As a result, the modeling does not account for such factors as impacts of temperature on emissions, differences in age distribution of the fleet, and differences in fuels (especially regarding ethanol fraction).

Many of the national-scale databases used for this application, including the meteorological and other input databases (for 2005) and the projected baseline criteria pollutant emissions data for 2030, were originally prepared by EPA for use in modeling exercises to support national rulemaking. However, as for any modeling database, it is expected that there are errors and uncertainties in the inputs that contribute to biases in the CMAQ results. This is especially true for the future-year modeling. For example, the meteorological conditions for 2005 might be representative of current conditions but would not reflect any effects of potential climate change in 2030. Similarly, the 2030 emissions are based on future estimates of population and economic and industrial activity, and contain uncertainties due to potential unknown social, political, and/or economic factors that could affect growth and activity and resulting future emissions.

E.4 HEALTH EFFECTS AND BENEFITS MODELING

This section presents the methods and results of the health effects and benefits modeling. Following the application of CMAQ for each action alternative, NHTSA processed the CMAQ-derived air quality estimates for input to the BenMAP health effects analysis tool, and used BenMAP to estimate the health impacts and monetized health-related benefits associated with the changes in air pollution simulated by CMAQ for each action alternative as compared to the No Action Alternative. The BenMAP tool includes health impact functions, which relate a change in the concentration of a pollutant with a change in the incidence of a health endpoint. BenMAP also calculates the economic value of health impacts. For this study, the health effects analysis considered the effects of ozone and $PM_{2.5}$.

E.4.1 Overview of the BenMAP Modeling System

BenMAP is an EPA-developed computer program that uses interpolation functions, population projections, health impact functions, and valuation functions to translate simulated changes in air pollution concentration into changes in health-related incidences and monetized health-related benefits. BenMAP is primarily intended as a tool for estimating the human health effects and economic benefits associated with changes in ambient air pollution. EPA originally developed this tool to analyze national-scale air quality regulations. The health benefits and monetary values derived using BenMAP are intended to inform policymakers by enabling the comparison of the benefits and costs of various regulatory measures (Abt Associates 2008).

BenMAP relies on the input of air quality information that can be used to calculate the change in ambient air pollution associated with a change in emissions. Typically, the results from two air quality modeling simulations (with different emission inputs) are used. In some cases, measured ambient air quality data can also be used.

BenMAP calculates health effects based on expected relationships between the change in concentration and certain health effects (also known as health endpoints), using concentration-response functions from epidemiology studies (Abt Associates 2008). The response functions are used together with population data to estimate health effects. For a model-based application, health effects are calculated grid cell by grid cell and then summed to obtain regional- and national-scale estimates. In its most basic form, the health effect for a given health endpoint is a function of the change in air concentration, concentration-response estimates, and population. Primary health endpoints include premature mortality, heart attacks, and chronic respiratory illnesses.

After estimating the change in adverse health effects associated with a given change in air quality, BenMAP calculates the monetary benefits associated with those changes (Abt Associates 2008). Simply, the economic value is based on the change in the incidence of a certain adverse health effect multiplied by the value of the health effect (on a per-incident or per-case basis). For example, the value associated with avoided premature mortality is typically calculated using the Value of Statistical Life (VSL), which is the monetary amount people are willing to pay to slightly reduce the risk of premature death. For other health effects, the medical costs of the illness are typically used to estimate value. The BenMAP database includes several different valuation functions for the health endpoints.

E.4.2 BenMAP Application Procedures for the NHTSA Modeling Analysis

NHTSA reformatted the CMAQ model output files for input to the BenMAP tool. They applied BenMAP separately for ozone and $PM_{2.5}$ and ran the model for both the ozone season (May through September) and the full annual period. Health impacts from reductions in air toxics are not estimated by BenMAP. The area covered by the BenMAP analysis is the continental United States. BenMAP includes population data at the census-tract level and algorithms for characterizing demographic changes (age distribution) over time. For this study, NHTSA used population estimates for 2030. This is consistent with the CMAQ simulation year of 2030.

BenMAP calculates the changes in health effects and monetized health-related benefits by comparing the results of two simulations. For this study, NHTSA used BenMAP to calculate the change in health effects and monetized health-related benefits for each action alternative compared to the No Action Alternative. This was done separately for Analysis A, Analysis B, and Cumulative Impacts, and resulted in nine BenMAP applications using the CMAQ results for:

- Alternative 2 and the No Action Alternative for Analysis A
- Alternative 3 and the No Action Alternative for Analysis A
- Alternative 4 and the No Action Alternative for Analysis A
- Alternative 2 and the No Action Alternative for Analysis B
- Alternative 3 and the No Action Alternative for Analysis B
- Alternative 4 and the No Action Alternative for Analysis B
- Alternative 2 and the No Action Alternative for Cumulative Impacts
- Alternative 3 and the No Action Alternative for Cumulative Impacts
- Alternative 4 and the No Action Alternative for Cumulative Impacts

Figures E.3.3.1-2, E.3.3.1-5, E.3.3.2-2, E.3.3.2-4, E.3.3.3-2, and E.3.3.3-4 show difference plots of the CMAQ-derived ozone and $PM_{2.5}$ concentrations for each of these pairs of simulations, and the corresponding BenMAP results reflect those differences.

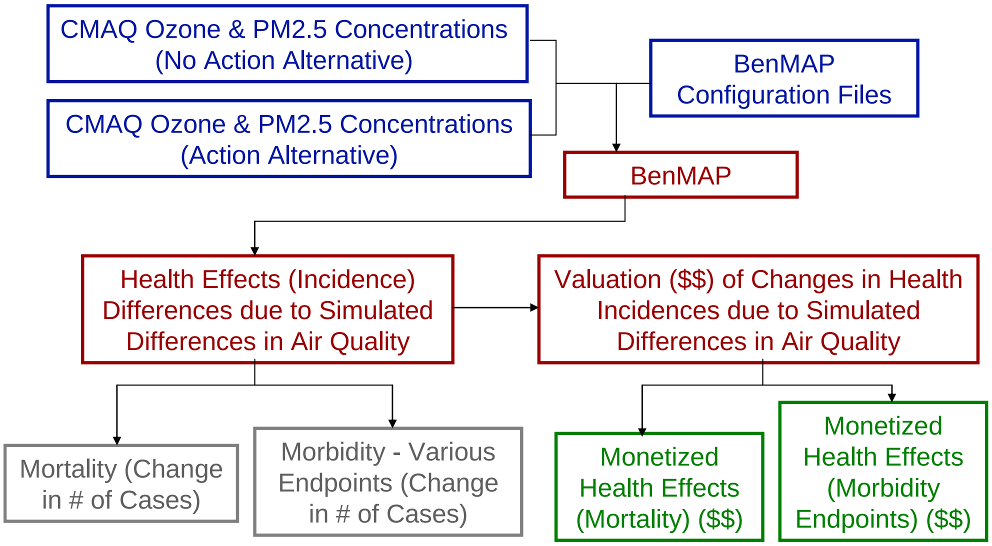
For each pollutant and simulation pair, the application of BenMAP involved four steps:

1. Incorporate the CMAQ modeling results into the air quality grid files required by BenMAP (air quality grid creation).
2. Calculate the change in the incidence of adverse health effects based on the differences in the CMAQ-derived ozone and $PM_{2.5}$ concentrations between the two simulations.
3. Aggregate the incidence results and calculate the economic value of the aggregated incidences.
4. Prepare tabular and graphical summaries; ensure the quality of and analyze the results.

In the air quality grid creation step, the CMAQ model results were used directly. NHTSA tested an option to use the model results together with observed data (the relative monitor and model method) and confirmed the outcome to be very similar to that for the chosen approach.

Figure E.4.2-1 illustrates the steps and components of the BenMAP application procedure.

Figure E.4.2-1. Schematic Diagram of the NHTSA CAFE BenMAP Health Effects and Benefits Analysis



E.4.2.1 Health Impact Functions

NHTSA used BenMAP to calculate reductions in both mortality and a range of non-fatal health effects (morbidity), based on epidemiological studies of a number of United States and Canadian populations.

BenMAP can estimate changes in a wide range of health impact endpoints associated with changes in ozone and $PM_{2.5}$ exposure. The endpoints are grouped broadly as mortality and morbidity. Mortality endpoints include changes in all-cause mortality, and mortality due to specific causes, such as cardiopulmonary disease. Morbidity endpoints include specific illnesses and symptoms (for example, asthma exacerbations), events requiring medical care (emergency room visits and hospital admissions), and adverse effects that involve lost work or restricted-activity days.

EPA has evaluated the literature related to the adverse effects of ozone and particulate matter exposures and identified a set of endpoints for which the associations are considered to be well established, and for which reliable exposure-response relationships have been developed (Abt Associates 2008). Tables E.4.2.1-1 and E.4.2.1-2 list the health endpoints used in this analysis for ozone and $PM_{2.5}$, respectively. The endpoints include changes in mortality (for both adults and infants), and a range of morbidity endpoints related to respiratory and cardiovascular diseases and symptoms, hospital admissions, and lost work or restricted-activity days. The tables provide the age range for each endpoint.

Pooled estimates for ozone include emergency room visits for respiratory symptoms and hospital admissions for respiratory symptoms.

Table E.4.2.1-1. Health Impact Functions Used to Estimate Ozone-related Health Effects

Endpoint	Author/Study/Location (If Applicable)	Age Range	Notes
Mortality, Non-Accidental	Ito et al. (2005)	0–99	a, b
Mortality, Non-Accidental	Schwartz (2005) (14 U.S. cities)	0–99	a,c
Mortality, Non-Accidental	Bell et al. (2004) (95 U.S. Cities)	0–99	a,b
Mortality, All Cause	Levy et al. (2005) (U.S. and non-U.S.)	0–99	a,c
Mortality, All Cause	Bell et al. (2005) (U.S. and non-U.S.)	0–99	a,b
Mortality, Cardiopulmonary	Huang et al. (2005) (19 U.S. cities)	0-99	a,b
Emergency Room Visits, Asthma	Jaffe et al. (2003) (Ohio cities)	5–34	a
Emergency Room Visits, Asthma	Peel et al. (2005) (Atlanta, GA)	0–99	a
Emergency Room Visits, Asthma	Wilson et al. (2005) (Portland, ME)	0–99	a
Emergency Room Visits, Asthma	Wilson et al. (2005) (Manchester, NH)	0–99	a
Hospital Admissions, All Respiratory	Burnett et al. (2001) (Toronto, CAN)	0–1	a,c
Hospital Admissions, All Respiratory	Schwartz ((New Haven, CT)	65–99	a,b
Hospital Admissions, All Respiratory	Schwartz (Tacoma, WA)	65–99	a,b
Hospital Admissions, Chronic Lung Disease	Moolgavkar et al. (1997) (Minneapolis, MN)	65–99	a,d
Hospital Admissions, Pneumonia	Moolgavkar et al. (1997) (Minneapolis, MN)	65–99	a,d
Hospital Admissions, Pneumonia	Schwartz (1994) (Detroit, MI)	65–99	a,d
Hospital Admissions, Pneumonia	Schwartz (1994)(Minneapolis, MN)	65–99	a,d
Hospital Admissions, Chronic Lung Disease (less Asthma)	Schwartz (1994) (Detroit, MI)	65–99	a,d
School Loss Days, All	Chen et al. (2000) (Washoe Co, NV)	5–17	a,f
School Loss Days, All	Gilliland et al. (2001) (Southern CA)	5–17	a,e
Worker Productivity Loss	Crocker & Horst (Nationwide)	18–64	a,d
Acute Respiratory Symptoms	Ostro & Rothschild (1989) (Nationwide)	18–64	a,g

a. Metric is daily maximum 8-hour ozone.
b. Metric is daily maximum 8-hour ozone. Warm season. 8-hour max from 24-hour mean.
c. Metric is daily maximum 8-hour ozone. Warm season. 8-hour max from 1-hour mean.
d. Metric is daily maximum 8-hour ozone. All year. 8-hour max from 24-hour mean.
e. Metric is daily maximum 8-hour ozone. All year. 8-hour max from 8-hour mean.
f. Metric is daily maximum 8-hour ozone. All year. 8-hour max from 1-hour mean.
g. Metric is daily maximum 8-hour ozone. 8-hour max from 1-hour mean.

Table E.4.2.1-2. Health Impact Functions Used to Estimate $PM_{2.5}$-related Health Effects

Endpoint	Author/Study/Location (If Applicable)	Age Range	Notes
Mortality, All Cause	Laden et al. (2006) (6 cities)	25–99	
Mortality, All Cause	Pope et al. (2002) (51 cities)	30–99	
Mortality, All Cause	Woodruff et al. (1997) (86 cities)	0–1	a
Mortality, All Cause	Woodruff et al. (1997) (86 cities)	0–1	d
Mortality, All Cause	Woodruff et al. (2006) (204 counties)	0–1	a
Mortality, All Cause	Woodruff et al. (2006) (204 counties)	0–1	
Mortality, All Cause	Krewski et al. (2009) (116 U.S. cities)	30–99	
Mortality, All Cause	Pope et al. (2002) (51 cities)	30–99	a
Mortality, All Cause	Pope et al. (2002) (51 cities)	30–99	b
Mortality, All Cause	Pope et al. (2002) (51 cities)	30–99	c
Mortality, All Cause	Pope et al. (2002) (51 cities)	30–99	d
Mortality, All Cause	Expert Elicitation (2006)	30–99	e
Mortality, All Cause	Expert Elicitation (2006)	30–99	f
Mortality, All Cause	Expert Elicitation (2006)	30–99	g
Mortality, All Cause	Expert Elicitation (2006)	30–99	h
Mortality, All Cause	Expert Elicitation (2006)	30–99	i
Mortality, All Cause	Expert Elicitation (2006)	30–99	j
Mortality, All Cause	Expert Elicitation (2006)	30–99	k
Mortality, Ischemic Heart Disease	Krewski et al. (2009) (116 U.S. cities)	30–99	
Mortality, Lung Cancer	Krewski et al. (2009) (116 U.S. cities)	30–99	

Table E.4.2.1-2. Health Impact Functions Used to Estimate $PM_{2.5}$-related Health Effects (continued)

Endpoint	Author/Study/Location (If Applicable)	Age Range	Notes
Chronic Bronchitis	Abbey et al. (1995) (San Francisco, San Diego, South Coast Air Basin)	27–99	
Chronic Bronchitis	Abbey et al. (1995) (San Francisco, San Diego, South Coast Air Basin)	27–99	a
Chronic Bronchitis	Abbey et al. (1995) (San Francisco, San Diego, South Coast Air Basin)	27–99	d
Acute Bronchitis	Dockery et al. (1996) (24 communities)	8–12	
Acute Bronchitis	Dockery et al. (1996) (24 communities)	8–12	d
Acute Myocardial Infarction, Nonfatal	Peters et al. (2001) (Boston, MA)	18–99	
Acute Myocardial Infarction, Nonfatal	Peters et al. (2001) (Boston, MA)	18–99	a
Hospital Admissions, Chronic Lung Disease	Moolgavkar (2003) (Los Angeles, CA)	65–99	a,e
Hospital Admissions, Chronic Lung Disease	Ito (2003) (Detroit, MI)	65–99	a,e
Hospital Admissions, Chronic Lung Disease (less Asthma)	Moolgavkar (2000) (Los Angeles, CA)	18–64	a,e
Hospital Admissions, Pneumonia	Ito (2003)	65–99	a,e
Hospital Admissions, Asthma	Norris et al. (1999) (Seattle, WA)	0–17	a,e
Hospital Admissions, All Cardiovascular (less Myocardial Infarctions)	Moolgavkar (2003)	18–64	a,e
Hospital Admissions, All Cardiovascular (less Myocardial Infarctions)	Moolgavkar(2003)	65–99	a,e
Hospital Admissions, Ischemic Heart Disease (less Myocardial Infarctions)	Ito (2003) (Detroit, MI)	65–99	a,e
Hospital Admissions, Dysrhythmia	Ito (2003) (Detroit, MI)	65–99	a,e
Hospital Admissions, Congestive Heart Failure	Ito (2003) (Detroit, MI)	65–99	a,e
Acute Bronchitis	Dockery, D.W. et al. (1996)	8–12	a,d
Emergency Room Visits, Asthma	Norris et al. (1999) Seattle, WA	0–17	a,e
Minor Restricted Activity Days	Ostro and Rothschild (1989) (Nationwide)	18–64	a,e
Lower Respiratory Symptoms	Schwartz and Neas (2000) (6 U.S. cities)	7–14	a,e
Asthma Exacerbation, Cough	Ostro et al. (2001) (Los Angeles)	6–18	a,e
Asthma Exacerbation, Wheeze	Ostro et al. (2001) (Los Angeles)	6–18	a,e
Asthma Exacerbation, Shortness of Breath	Ostro et al. (2001) (Los Angeles)	6–18	a,e
Work Loss Days	Ostro (1987) (Nationwide)	18–64	a,e
Upper Respiratory Symptoms	Pope et al. (1987) (Utah Valley)	9–11	a,e

a. Adjusted Coefficient With 10 µg Threshold
b. Adjusted Coefficient With 12 µg Threshold
c. Adjusted Coefficient With 15 µg Threshold
d. Adjusted Coefficient With 7.5 µg Threshold
e. Full Range
f. Range from > 10 to 30 µg
g. Range from >16 to 30 (no threshold)
h. Range from >7 to 30
i. Range from 4 to 7 µg
j. Range from 4 to 10 µg
k. Range from 4 to 16 µg (no threshold)

Pooled estimates for $PM_{2.5}$ include acute myocardial infarction, hospital admissions for respiratory symptoms, and hospital admissions for cardiovascular symptoms. In the health incidence calculation step, no threshold value was specified, consistent with EPA guidance. The optional use of a threshold value can be to examine the sensitivity of particulate matter-related health impact estimates to different assumed thresholds. The results options for this study include the mean value, incremental percentile values, and standard deviation.

E.4.2.2 Valuation Metrics

NHTSA also used BenMAP to estimate monetized health-related benefits (based on VSL studies, lost wages, health care expenses, and “willingness to pay”) associated with the health impacts. These estimates are derived using a set of monetary surrogates for the various health effects developed by EPA and public health researchers. BenMAP also tracks changes over time in willingness to pay for reductions in health risks, and includes adjustment factors that incorporate the effect of inflation on health-care costs.

The assessment of monetized health-related benefits involves assigning monetary values to each health endpoint, and totaling all benefits associated with changes in pollutant exposures. Different valuation methods are used for the various health endpoints. The monetary surrogate value for mortality is derived using a VSL approach; that is, the monetary cost of a single “statistical” death (Abt Associates 2008). The VSL used for this analysis is built into BenMAP and is $6.3 million (in 2000-equivalent dollars).

Valuation methods for morbidity endpoints (non-fatal health effects) include approaches referred to as cost of illness (COI), willingness to pay (WTP), and lost wages or productivity (Abt Associates 2008). COI estimates comprise a range of approaches, which account for the costs of medical care and in some cases lost wages. WTP approaches refer to methods in which voluntary payments to avoid disease are directly or indirectly estimated and used to estimate monetized health-related benefits. Finally, lost-productivity methods value the time lost to illness using wage rates or the estimated value of leisure or school time (Abt Associates 2008). For all endpoints, the total monetized health-related benefit for a given endpoint is estimated by multiplying the monetary values for that endpoint by the estimated change in the number of “cases” of the endpoint. For most studies, morbidity values are small compared to the mortality values. Therefore, the specific valuation methods used for morbidity have only a small effect on the overall monetized health-related benefits estimates.

Tables E.4.2.2-1 and E.4.2.2-2 list the endpoints and methods used for the valuation portion of the analysis for ozone and $PM_{2.5}$, respectively. The endpoints include monetized health-related benefits associated with changes in mortality, and a range of morbidity endpoints. For consistency with EPA’s RIA, all monetized health-related benefits results for this analysis are presented in 2010-equivalent dollars.

Table E.4.2.2-1. Valuation Functions Used to Estimate Ozone-related Monetized Health-related Benefits

Endpoint	Valuation Method	Notes
Mortality, Non-Accidental	VSL	a
Mortality, All Cause	VSL	a
Mortality, Cardiopulmonary	VSL	a
Hospital Admissions, Respiratory	COI	b
Hospital Admissions, Respiratory	COI	b
Emergency Room Visits, Respiratory	COI	c,d
School Loss Days	Productivity	
Worker productivity loss	Productivity	
Acute Respiratory Symptoms	WTP	

a. Based on 26 value-of-life studies.
b. Medical costs plus lost wages.
c. Source: Stanford 1999.
d. Source: Smith et al. 1997.

Table E.4.2.2-2. Valuation Functions Used to Estimate $PM_{2.5}$-related Monetized Health-Related Benefits

Endpoint	Valuation Method	Notes
Mortality	VSL	a
Chronic Bronchitis	WTP	b
Acute Myocardial Infarction	COI	c, i, m
Hospital Admissions, Chronic Lung Disease	COI	d
Hospital Admissions, Pneumonia	COI	d
Hospital Admissions, Respiratory	COI	d
Hospital Admissions, Cardiovascular	COI	d
Emergency Room Visits, Respiratory	COI	k, l
Acute Bronchitis	WTP	e, f
Lower Respiratory Symptoms	WTP	e, f
Upper Respiratory Symptoms	WTP	e, f
Acute Respiratory Symptoms	WTP	e, f
Work Loss Days	Productivity	g
Asthma Exacerbation	WTP	h, j

a. Based on 26 value-of-life studies.
b. Average severity.
c. 5 years medicine, 5 years wages, 3 percent discount rate.
d. Medical costs plus lost wages.
e. 1-day illness.
f. Contingent valuation (CV) studies.
g. Median daily wage, county-specific.
h. Bad asthma day.
i. Source: Russell 1998.
j. Source: Rowe Chestnut 1986.
k. Source: Stanford 1999.
l. Source: Smith et al. 1997.
m. Source: Wittels 1990.

In the aggregation and valuation step, the results were aggregated for the national scale. Default options were applied in the aggregation and pooling of the results. Similarly, EPA standard inflation values (defaults) were used for the valuation. The results are given in 2010-equivalent dollars.

E.4.2.3 Post-processing and Quality Assurance Procedures

As a first step in the quality assurance process for the BenMAP application procedures and results, NHTSA prepared a protocol document outlining each application step and then used the protocol document as a checklist for each application and to ensure quality. Following the application of BenMAP, NHTSA duplicated a subset of the BenMAP runs using another computer and confirmed the results to be the same. Finally, NHTSA checked the results for each simulation pair for consistency with emissions and the CMAQ modeling results.

NHTSA then prepared tabular and graphical summaries of the results, as presented in the following sections, and systematically checked the contents of the tables and charts by comparing the values with the raw BenMAP report files.

E.4.3 BenMAP Results

As noted earlier, NHTSA used BenMAP to estimate the reduction in the incidence of various health-related endpoints, and to develop a monetized estimate of the health-related benefits for each action alternative. The remainder of this section provides the incidence and valuation results. The health incidence results in this section are the BenMAP-derived mean values. The valuation estimates reflect both an income growth adjustment and a time lag between exposure and $PM_{2.5}$ mortality.

The income growth adjustment accounts for expected growth in real income over time. Economic theory suggests that WTP for most goods and services (such as environmental protection) will increase if income increases. To account for growth in income through 2030, the BenMAP-derived reductions were multiplied by 1.23 for long-term mortality (mortality that occurs over approximately 20 years into the future, but is attributable to emissions that occur in the present), 1.27 for chronic health impacts, and 1.08 for minor health impacts.

The valuation results for $PM_{2.5}$ assume that there is a time lag between changes in $PM_{2.5}$ concentration and changes in $PM_{2.5}$ mortality. To account for this, monetized health-related benefits occurring in the future are discounted. For this analysis, the BenMAP-derived reductions were multiplied by 0.91 to achieve a 3 percent discount rate and by 0.82 to achieve a 7 percent discount rate. There are no similar adjustments for ozone or for the morbidity endpoints.

All of the incidence and valuation results are rounded to two significant figures.

E.4.3.1 Direct and Indirect Impacts, Analysis A

Tables E.2.3-1 and E.2.3-2 list the emissions associated with the action alternatives for Analysis A.

E.4.3.1.1 Ozone

Table E.4.3.1-1 lists BenMAP results for ozone mortality for the three action alternatives for Analysis A. The reductions in premature mortality incidence are for the entire continental United States. There are no results for the No Action Alternative because this is the baseline to which the CMAQ results under the action alternatives were compared within the BenMAP tool (*see* the list of simulation pairs in Section E.4.2).

Table E.4.3.1-1. BenMAP Aggregated/Pooled Incidence Results for Ozone-related Mortality: Estimated Nationwide Reduction in Premature Mortality, Direct and Indirect Impacts, Analysis A

	Reduction in Number of Cases		
Epidemiology Study	**Alternative 2**	**Alternative 3**	**Alternative 4**
Mortality, Non-Accidental (Ito et al.)	11	17	54
Mortality, Non-Accidental (Schwartz)	4	6	19
Mortality, Non-Accidental (Bell et al.)	2	4	12
Mortality, All Cause (Levy et al.)	11	17	55
Mortality, All Cause (Bell et al.)	8	12	39
Mortality, Cardiopulmonary (Huang)	3	6	18

The results vary by epidemiology study and by alternative. Alternative 2 is associated with fewer reductions in mortality incidence than the other two action alternatives, and Alternative 4 is associated with more reductions than the other action alternatives. Under the Preferred Alternative, the reduction in mortality incidence due to the simulated change in ozone concentration ranges from 4 to 17 cases, based on study.

Table E.4.3.1-2 lists the BenMAP results for other ozone-related health effects and associated endpoints (morbidity) for Analysis A. In some cases, the studies cover different age groups, as indicated. The reductions in incidence for all endpoints are for the entire continental United States.

Table E.4.3.1-2. BenMAP Aggregated/Pooled Incidence Results for Ozone-related Morbidity: Estimated Nationwide Reduction in Various Morbidity Endpoints, Direct and Indirect Impacts, Analysis A

Epidemiology Study	Reduction in Number of Cases		
	Alternative 2	Alternative 3	Alternative 4
Emergency room visits, respiratory	9	15	44
Hospital admissions, respiratory	29	45	130
School loss days (age 5–17)	5,300	8,300	25,000
Minor restricted-activity days (age 18–65)	16,000	26,000	76,000
Worker productivity loss	1.6.E+05	2.2.E+05	7.7.E+05

For all endpoints considered here, the fewest reductions are associated with Alternative 2 and the most reductions are associated with Alternative 4. Under the Preferred Alternative, emergency room visits for respiratory problems are reduced by 15 cases and hospital admissions for respiratory problems are reduced by 45 cases due to the change in simulated ozone concentration.

Table E.4.3.1-3 lists BenMAP valuation results for ozone mortality under the action alternatives for Analysis A. The monetized health-related benefits represent nationwide changes in millions of U.S. 2010-equivalent dollars. As noted above, no discount rate is applied for ozone mortality.

Table E.4.3.1-3. BenMAP-derived Nationwide Monetized Health-related Benefits for Ozone-related Mortality: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Direct and Indirect Impacts, Analysis A

Epidemiology Study	Reduction		
	Alternative 2	Alternative 3	Alternative 4
Non-accidental (Ito et al.)	100	160	530
Non-accidental (Bell et al. (U.S. cities))	23	36	120
Non-accidental (Schwartz et al.)	36	57	180
All causes (Levy et al.)	110	170	540
All causes (Bell et al.)	76	120	390
Cardiopulmonary	34	54	180

Estimates of monetized health-related benefits under the Preferred Alternative range from 36 to 170 million dollars for the ozone-related mortality valuation. The estimated benefits under Alternative 2 are lower than those under Alternative 3, and those under Alternative 4 are higher than those under Alternative 3 by about a factor of 3.

Table E.4.3.1-4 lists BenMAP valuation results for other ozone-related health effects and associated endpoints (morbidity) for Analysis A.

Table E.4.3.1-4. BenMAP-derived Nationwide Monetized Health-related Benefits for Ozone-related Morbidity: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Various Morbidity, Direct and Indirect Impacts, Analysis A

Epidemiology Study	Reduction		
	Alternative 2	Alternative 3	Alternative 4
Emergency room visits, respiratory	0	0	0
Hospital admissions, respiratory	1	1	3
School loss days (age 0–17)	1	1	2
Worker productivity loss	0	0	1
Acute respiratory symptoms (age 18–99)	1	2	5

For the endpoints considered here, the monetized health-related benefits are smallest under Alternative 2 and slightly greater for each successive action alternative. Monetized health-related benefits under the Preferred Alternative range from less than 1 million dollars, for a reduction in emergency room visits related to respiratory symptoms and worker productivity loss, to 2 million dollars for a reduction in acute respiratory symptoms.

E.4.3.1.2 $PM_{2.5}$

Table E.4.3.1-5 lists BenMAP results for $PM_{2.5}$ mortality under the actions alternatives for Analysis A. The mortality estimates are based on both epidemiology literature and expert elicitation in which experts were asked to develop estimates of the increment in mortality that would be associated with increments of $PM_{2.5}$ exposures, based on their understanding of the epidemiological literature taken as a whole (Abt Associates 2008).

Table E.4.3.1-5. BenMAP Aggregated/Pooled Incidence Results for $PM_{2.5}$-related Mortality: Estimated Nationwide Reduction in Premature Mortality, Direct and Indirect Impacts, Analysis A

	Reduction in Number of Cases		
	Alternative 2	**Alternative 3**	**Alternative 4**
Epidemiology Literature			
Harvard six-city study (Laden et al.)	240	370	500
American Cancer Society (ACS) study (Pope et al.)	94	140	200
Infant mortality study (Woodruff et al.)	0	1	1
Expert Elicitation			
Expert A	260	390	530
Expert B	190	290	390
Expert C	210	330	440
Expert D	140	210	290
Expert E	320	500	670
Expert F	150	240	330
Expert G	110	170	230
Expert H	140	210	290
Expert I	200	310	410
Expert J	180	270	370
Expert K	29	45	61
Expert L	120	190	250

The results vary by study due to the use of different study populations and exposure-response relationships, and by alternative. Alternative 2 is associated with the fewest reductions in mortality incidence and Alternative 4 is associated with the most reductions. Under the Preferred Alternative, the reduction in adult mortality incidence due to the simulated change in $PM_{2.5}$ concentration ranges from 140 to 370 cases for the epidemiology studies and from 45 to 500 for the expert elicitation studies.

Table E.4.3.1-6 lists BenMAP results for other $PM_{2.5}$-related health effects and associated endpoints (morbidity) for Analysis A.

Table E.4.3.1-6. BenMAP Aggregated/Pooled Incidence Results for $PM_{2.5}$-related Morbidity: Estimated Nationwide Reduction in Various Morbidity, Direct and Indirect Impacts, Analysis A

Epidemiology Study	Reduction in Number of Cases		
	Alternative 2	Alternative 3	Alternative 4
Chronic bronchitis (age >= 27)	67	100	140
Emergency room visits for asthma (age <17)	67	100	150
Acute bronchitis (age 8–12)	150	230	310
Asthma exacerbation (age 6–18)	3,100	4,700	6,400
Lower respiratory symptoms (age 7–14)	1,900	2,900	3,900
Upper respiratory symptoms (age 9–11)	1,400	2,200	3,000
Minor restricted-activity days (age 18–64)	72,000	110,000	150,000
Work loss days (age 18–64)	12,000	19,000	25,000
Nonfatal myocardial infarction (age >17)	120	180	240
Hospital admissions - respiratory (all ages)	18	28	38
Hospital admissions - cardiovascular (age >17)	42	64	88

For all endpoints considered here, the fewest reductions are associated with Alternative 2 and the most reductions are associated with Alternative 4. Under the Preferred Alternative, emergency room visits for asthma are reduced by 100 cases and hospital admissions for respiratory problems are reduced by 28 cases due to the change in simulated $PM_{2.5}$ concentration.

Table E.4.3.1-7 lists BenMAP valuation results for $PM_{2.5}$ related mortality under the action alternatives for Analysis A with a 3 percent discount rate. The monetized health-related benefits represent nationwide changes in millions of U.S. 2010-equivalent dollars.

Table E.4.3.1-7. BenMAP Monetized Health-related Benefits for $PM_{2.5}$-related Mortality with a 3 Percent Discount Rate: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Direct and Indirect Impacts, Analysis A

	Reduction		
	Alternative 2	Alternative 3	Alternative 4
Epidemiology Literature			
Harvard six-city study (Laden et al.)	2,200	3,300	4,500
ACS study (Pope et al.)	840	1,300	1,700
Infant mortality study (Woodruff et al.)	3	5	6
Expert Elicitation			
Expert A	2,300	3,500	4,700
Expert B	1,700	2,600	3,500
Expert C	1,900	2,900	3,900
Expert D	1,200	1,900	2,600
Expert E	2,900	4,400	6,000
Expert F	1,400	2,100	2,900
Expert G	1,000	1,500	2,100
Expert H	1,200	1,900	2,600
Expert I	1,800	2,700	3,700
Expert J	1,600	2,400	3,300
Expert K	260	400	540
Expert L	1,100	1,600	2,300

The monetized health-related benefits under the Preferred Alternative range from 1.3 to 3.3 billion dollars for premature mortality (not including infant mortality) based on epidemiological studies (Pope et al. 2002 and Laden et al. 2006 in Abt Associates 2008) and from 400 million to 4.4 billion dollars for the expert elicitation estimates. The monetized health-related benefits are lowest under Alternative 2.

The estimated benefits under Alternative 2 are lower than those under the Preferred Alternative, and those under Alternative 4 are higher than those under Alternative 3 by about 30 percent.

Table E.4.3.1-8 lists BenMAP valuation results for $PM_{2.5}$-related mortality for Analysis A with a 7 percent discount rate.

Table E.4.3.1-8. BenMAP Monetized Health-related Benefits for $PM_{2.5}$-related Mortality with a 7 Percent Discount Rate: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Direct and Indirect Impacts, Analysis A

	Reduction		
	Alternative 2	**Alternative 3**	**Alternative 4**
Epidemiology Literature			
Harvard six-city study (Laden et al.)	1,900	3,000	4,000
ACS study (Pope et al.)	760	1,200	1,600
Infant mortality study (Woodruff et al.)	3	4	5
Expert Elicitation			
Expert A	2,000	3,200	4,300
Expert B	1,500	2,300	3,200
Expert C	1,700	2,600	3,500
Expert D	1,100	1,700	2,300
Expert E	2,600	4,000	5,400
Expert F	1,200	1,900	2,600
Expert G	900	1,400	1,900
Expert H	1,100	1,700	2,300
Expert I	1,600	2,500	3,300
Expert J	1,400	2,200	2,900
Expert K	230	360	490
Expert L	970	1,500	2,000

With the 7 percent discount, the monetized health-related benefits under the Preferred Alternative range from 1.2 to 3 billion dollars for premature mortality (not including infant mortality) based on epidemiological studies (Pope et al. 2002 and Laden et al. 2006 in Abt Associates 2008) and from 360 million to 4 billion dollars for the expert elicitation estimates.

Table E.4.3.1-9 lists BenMAP valuation results for other $PM_{2.5}$-related health effects and associated endpoints (morbidity) for Analysis A.

Table E.4.3.1-9. BenMAP-derived Nationwide Monetized Health-related Benefits for $PM_{2.5}$-related Morbidity: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Various Morbidity Endpoints, Direct and Indirect Impacts, Analysis A

	Reduction		
Epidemiology Study	**Alternative 2**	**Alternative 3**	**Alternative 4**
Chronic bronchitis (age >=27)	36	56	76
Emergency room visits for asthma (age <17)	0	0	0
Acute bronchitis (age 8–12)	0	0	0
Asthma exacerbation (age 6–18)	0	0	0
Lower respiratory symptoms (age 7–14)	0	0	0
Upper respiratory symptoms (age 9–11)	0	0	0
Minor restricted-activity days (age 18–64)	5	8	10
Work loss days (age 18–64)	2	3	4
Nonfatal myocardial infarction (age >17)	13	20	27
Hospital admissions - respiratory (all ages)	0	0	1
Hospital admissions - cardiovascular (age >17)	1	1	1

For the endpoints considered here, the monetized health-related benefits are smallest under Alternative 2 and slightly greater for each successive action alternative. The greatest reductions in monetized health-related benefits are associated with fewer incidences of chronic bronchitis and non-fatal myocardial infarctions.

E.4.3.2 Direct and Indirect Impacts, Analysis B

Tables E.2.3-1 and E.2.3-2 list the emissions associated with the action alternatives under Analysis B.

E.4.3.2.1 Ozone

Table E.4.3.2-1 lists BenMAP results for ozone mortality under the three action alternatives for Analysis B. The reductions in premature mortality incidence are for the entire continental United States.

Table E.4.3.2-1. BenMAP Aggregated/Pooled Incidence Results for Ozone-related Mortality: Estimated Nationwide Reduction in Premature Mortality, Direct and Indirect Impacts, Analysis B

	Reduction in Number of Cases		
Epidemiology Study	**Alternative 2**	**Alternative 3**	**Alternative 4**
Mortality, Non-Accidental (Ito et al.)	10	11	48
Mortality, Non-Accidental (Schwartz)	3	4	16
Mortality, Non-Accidental (Bell et al.)	2	3	11
Mortality, All Cause (Levy et al.)	10	12	49
Mortality, All Cause (Bell et al.)	7	8	35
Mortality, Cardiopulmonary (Huang)	3	4	16

The results vary by epidemiology study and by alternative. Alternative 2 is associated with fewer reductions in mortality incidence than the other two action alternatives, and Alternative 4 is associated with more reductions than the other action alternatives. Under the Preferred Alternative, the reduction in mortality incidence due to the simulated change in ozone concentration ranges from 3 to 12 cases.

Table E.4.3.2-2 lists BenMAP results for other ozone-related health effects and associated endpoints (morbidity) for Analysis B. The reductions in incidence for all endpoints are for the entire continental United States.

Table E.4.3.2-2. BenMAP Aggregated/Pooled Incidence Results for Ozone-related Morbidity: Estimated Nationwide Reduction in Various Morbidity Endpoints, Direct and Indirect Impacts, Analysis B

	Reduction in Number of Cases		
Epidemiology Study	**Alternative 2**	**Alternative 3**	**Alternative 4**
Emergency room visits, respiratory	8	11	40
Hospital admissions, respiratory	27	31	110
School loss days (age 5–17)	4,900	6,000	22,000
Minor restricted-activity days (age 18–65)	15,000	19,000	68,000
Worker productivity loss	1.4.E+05	1.4.E+05	6.5.E+05

For all endpoints considered here, the fewest reductions are associated with Alternative 2 and the most reductions are associated with Alternative 4. Under the Preferred Alternative, emergency room visits for respiratory problems are reduced by 11 cases and hospital admissions for respiratory problems are reduced by 31 cases due to the change in simulated ozone concentration.

Table E.4.3.2-3 lists BenMAP valuation results for ozone mortality under the three action alternatives for Analysis B. The monetized health-related benefits represent nationwide changes in millions of U.S. 2010-equivalent dollars.

Table E.4.3.2-3. BenMAP-derived Nationwide Monetized Health-related Benefits for Ozone-related Mortality: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Direct and Indirect Impacts, Analysis B

Epidemiology Study	Reduction		
	Alternative 2	Alternative 3	Alternative 4
Non-accidental (Ito et al.)	96	110	470
Non-accidental (Bell et al. (U.S. cities))	21	25	110
Non-accidental (Schwartz et al.)	33	39	160
All causes (Levy et al.)	99	120	480
All causes (Bell et al.)	70	81	340
Cardiopulmonary	31	37	160

The calculated monetized health-related benefits under the Preferred Alternative range from 25 to 120 million dollars for the ozone-related mortality valuation estimates. The estimated benefits under Alternative 2 are lower than those under Alternative 3, and those under Alternative 4 are higher than those under Alternative 3 by about a factor of 4.

Table E.4.3.2-4 lists BenMAP valuation results for other ozone-related health effects and associated endpoints (morbidity) for Analysis B.

Table E.4.3.2-4. BenMAP-derived Nationwide Monetized Health-related Benefits for Ozone-related Morbidity: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Various Morbidity, Direct and Indirect Impacts, Analysis B

Epidemiology Study	Reduction		
	Alternative 2	Alternative 3	Alternative 4
Emergency room visits, respiratory	0	0	0
Hospital admissions, respiratory	1	1	3
School loss days (age 0–17)	0	1	2
Worker productivity loss	0	0	1
Acute respiratory symptoms (age 18–99)	1	1	5

For the endpoints considered here, the monetized health-related benefits are smallest under Alternative 2 and slightly greater for each successive action alternative. The monetized health-related benefits under the Preferred Alternative range from less than 1 million dollars, for emergency room visits for respiratory symptoms and worker productivity loss, to 1 million dollars for the remaining endpoints.

E.4.3.2.2 PM$_{2.5}$

Table 4.3.2-5 lists BenMAP results for PM$_{2.5}$ mortality under the three action alternatives for Analysis B. The mortality estimates are based on both epidemiology literature and expert elicitation in which experts were asked to develop estimates of the increment in mortality that would be associated with increments of PM$_{2.5}$ exposures, based on their understanding of the epidemiological literature taken as a whole (Abt Associates 2008).

Table E.4.3.2-5. BenMAP Aggregated/Pooled Incidence Results for $PM_{2.5}$-related Mortality: Estimated Nationwide Reduction in Premature Mortality, Direct and Indirect Impacts, Analysis B

	Reduction in Number of Cases		
	Alternative 2	Alternative 3	Alternative 4
Epidemiology Literature			
Harvard six-city study (Laden et al.)	220	330	470
ACS study (Pope et al.)	87	130	180
Infant mortality study (Woodruff et al.)	0	0	1
Expert Elicitation			
Expert A	240	350	500
Expert B	170	260	370
Expert C	200	290	410
Expert D	130	190	270
Expert E	300	440	630
Expert F	140	210	300
Expert G	100	160	220
Expert H	130	190	270
Expert I	180	270	390
Expert J	160	240	340
Expert K	27	40	57
Expert L	110	170	240

The results vary by study due to the use of different study populations and exposure-response relationships, and by alternative. Alternative 2 is associated with the fewest reductions in mortality incidence and Alternative 4 is associated with the most. Under the Preferred Alternative, the reduction in adult mortality incidence due to the simulated change in $PM_{2.5}$ concentration ranges from 130 to 330 cases for the epidemiology studies and from 40 to 440 for the expert elicitation studies.

Table E.4.3.2-6 lists BenMAP results for other $PM_{2.5}$-related health effects and associated endpoints (morbidity) for Analysis B.

Table E.4.3.2-6. BenMAP Aggregated/Pooled Incidence Results for $PM_{2.5}$-related Morbidity: Estimated Nationwide Reduction in Various Morbidity, Direct and Indirect Impacts, Analysis B

	Reduction in Number of Cases		
Epidemiology Study	Alternative 2	Alternative 3	Alternative 4
Chronic bronchitis (age >=27)	62	90	130
Emergency room visits for asthma (age <17)	62	90	140
Acute bronchitis (age 8–12)	140	210	290
Asthma exacerbation (age 6–18)	2,900	4,300	6,000
Lower respiratory symptoms (age 7–14)	1,700	2,600	3,700
Upper respiratory symptoms (age 9–11)	1,300	2,000	2,800
Minor restricted-activity days (age 18–64)	66,000	99,000	140,000
Work loss days (age 18–64)	11,000	17,000	24,000
Nonfatal myocardial infarction (age >17)	100	160	220
Hospital admissions - respiratory (all ages)	17	25	35
Hospital admissions - cardiovascular (age >17)	39	58	82

For all endpoints considered here, the fewest reductions are associated with Alternative 2 and the most reductions are associated with Alternative 4. Under the Preferred Alternative, emergency room visits for asthma are reduced by 90 cases and hospital admissions for respiratory problems are reduced by 25 cases due to the change in simulated $PM_{2.5}$ concentration.

Table E.4.3.2-7 lists BenMAP valuation results for $PM_{2.5}$-related mortality under the three action alternatives for Analysis B. The monetized health-related benefits represent nationwide changes in millions of U.S. 2010-equivalent dollars.

Table E.4.3.2-7. BenMAP Monetized Health-related Benefits for $PM_{2.5}$-related Mortality with a 3 Percent Discount Rate: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Direct and Indirect Impacts, Analysis B

	Reduction		
	Alternative 2	**Alternative 3**	**Alternative 4**
Epidemiology Literature			
Harvard six-city study (Laden et al.)	2,000	3,000	4,200
ACS study (Pope et al.)	780	1,200	1,600
Infant mortality study (Woodruff et al.)	3	4	6
Expert Elicitation			
Expert A	2,100	3,100	4,400
Expert B	1,600	2,300	3,300
Expert C	1,700	2,600	3,700
Expert D	1,100	1,700	2,400
Expert E	2,700	4,000	5,600
Expert F	1,300	1,900	2,700
Expert G	930	1,400	2,000
Expert H	1,100	1,700	2,400
Expert I	1,600	2,400	3,400
Expert J	1,500	2,200	3,000
Expert K	240	350	500
Expert L	990	1,500	2,100

The monetized health-related benefits under the Preferred Alternative range from 1.2 to 3 billion dollars for premature mortality (not including infant mortality) based on epidemiological studies (Pope et al. 2002 and Laden et al. 2006 in Abt Associates) and from 350 million to 4 billion dollars for the expert elicitation estimates. The monetized health-related benefits are lowest under Alternative 2. The estimated benefits under Alternative 2 are lower than those under the Preferred Alternative, and those under Alternative 4 are higher than those under Alternative 3 by about 40 percent.

Table E.4.3.2-8 lists BenMAP valuation results for $PM_{2.5}$-related mortality for Analysis B with a 7 percent discount rate.

With the 7 percent discount, the monetized health-related benefits under the Preferred Alternative range from 1 to 2.7 billion dollars for premature mortality (not including infant mortality) based on epidemiological studies (Pope et al. 2002 and Laden et al. 2006 in Abt Associates) and from 320 million to 3.6 billion dollars for the expert elicitation estimates.

Table E.4.3.2-9 lists BenMAP valuation results for other $PM_{2.5}$-related health effects and associated endpoints (morbidity) for Analysis B.

For the endpoints considered here, the monetized health-related benefits are smallest under Alternative 2 and slightly greater for each successive action alternative. The greatest reductions in monetized health-related benefits are associated with fewer incidences of chronic bronchitis and non-fatal myocardial infarctions.

Table E.4.3.2-8. BenMAP Monetized Health-related Benefits for $PM_{2.5}$-related Mortality with a 7 Percent Discount Rate: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Direct and Indirect Impacts, Analysis B

	Reduction		
	Alternative 2	Alternative 3	Alternative 4
Epidemiology Literature			
Harvard six-city study (Laden et al.)	1,800	2,700	3,800
ACS study (Pope et al.)	700	1,000	1,500
Infant mortality study (Woodruff et al.)	3	4	5
Expert Elicitation			
Expert A	1,900	2,800	4,000
Expert B	1,400	2,100	3,000
Expert C	1,600	2,300	3,300
Expert D	1,000	1,500	2,200
Expert E	2,400	3,600	5,000
Expert F	1,100	1,700	2,400
Expert G	840	1,200	1,800
Expert H	1,000	1,500	2,200
Expert I	1,500	2,200	3,100
Expert J	1,300	1,900	2,700
Expert K	210	320	450
Expert L	890	1,300	1,900

Table E.4.3.2-9. BenMAP-derived Nationwide Monetized Health-related Benefits for $PM_{2.5}$-related Morbidity: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Various Morbidity Endpoints, Direct and Indirect Impacts, Analysis B

	Reduction		
Epidemiology Study	Alternative 2	Alternative 3	Alternative 4
Chronic bronchitis (age >=27)	33	50	71
Emergency room visits for asthma (age <17)	0	0	0
Acute bronchitis (age 8–12)	0	0	0
Asthma exacerbation (age 6–18)	0	0	0
Lower respiratory symptoms (age 7–14)	0	0	0
Upper respiratory symptoms (age 9–11)	0	0	0
Minor restricted-activity days (age 18–64)	5	7	10
Work loss days (age 18–64)	2	3	4
Nonfatal myocardial infarction (age >17)	12	18	25
Hospital admissions - respiratory (all ages)	0	0	1
Hospital admissions - cardiovascular (age >17)	1	1	1

E.4.3.3 Cumulative Impacts

Tables E.2.3-1 and E.2.3-2 list emissions associated with the action alternatives for Cumulative Impacts.

E.4.3.3.1 Ozone

Table E.4.3.3-1 lists BenMAP results for ozone mortality under the three action alternatives for Cumulative Impacts. The reductions in premature mortality incidence are for the entire continental United States.

Table E.4.3.3-1. BenMAP Aggregated/Pooled Incidence Results for Ozone-related Mortality: Estimated Nationwide Reduction in Premature Mortality, Cumulative Impacts

	Reduction in Number of Cases		
Epidemiology Study	**Alternative 2**	**Alternative 3**	**Alternative 4**
Mortality, Non-Accidental (Ito et al.)	13	14	51
Mortality, Non-Accidental (Schwartz)	4	5	18
Mortality, Non-Accidental (Bell et al.)	3	3	11
Mortality, All Cause (Levy et al.)	13	15	52
Mortality, All Cause (Bell et al.)	9	11	37
Mortality, Cardiopulmonary (Huang)	4	5	17

The results vary by epidemiology study and by alternative. Alternative 2 is associated with fewer reductions in mortality incidence than the other two action alternatives, and Alternative 4 is associated with more reductions than the other action alternatives. Under the Preferred Alternative, the reduction in mortality incidence due to the simulated change in ozone concentration ranges from 3 to 15 cases.

Table E.4.3.3-2 lists BenMAP results for other ozone-related health effects and associated endpoints (morbidity) for Cumulative Impacts. The reductions in incidence for all endpoints are for the entire continental United States.

Table E.4.3.3-2. BenMAP Aggregated/Pooled Incidence Results for Ozone-related Morbidity: Estimated Nationwide Reduction in Various Morbidity Endpoints, Cumulative Impacts

	Reduction in Number of Cases		
Epidemiology Study	**Alternative 2**	**Alternative 3**	**Alternative 4**
Emergency room visits, respiratory	11	14	43
Hospital admissions, respiratory	35	39	120
School loss days (age 5–17)	6,300	7,400	23,000
Minor restricted-activity days (age 18–65)	19,000	23,000	72,000
Worker productivity loss	1.9.E+05	1.9.E+05	7.0.E+05

For the endpoints considered here, the fewest reductions are associated with Alternative 2 and the most reductions are associated with Alternative 4. Under the Preferred Alternative, emergency room visits for respiratory problems are reduced by 14 cases and hospital admissions for respiratory problems are reduced by 39 cases due to the change in simulated ozone concentration.

Table E.4.3.3-3 lists BenMAP valuation results for ozone mortality under the three action alternatives for Cumulative Impacts. The monetized health-related benefits represent nationwide changes in millions of U.S. 2010-equivalent dollars.

Table E.4.3.3-3. BenMAP-derived Nationwide Monetized Health-related Benefits for Ozone-related Mortality: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Cumulative Impacts

	Reduction		
Epidemiology Study	**Alternative 2**	**Alternative 3**	**Alternative 4**
Non-accidental (Ito et al.)	130	140	500
Non-accidental (Bell et al. (U.S. cities))	28	32	110
Non-accidental (Schwartz et al.)	43	49	170
All causes (Levy et al.)	130	150	510
All causes (Bell et al.)	92	100	360
Cardiopulmonary	41	47	170

The calculated monetized health-related benefits under the Preferred Alternative range from 32 to 150 million dollars for the ozone-related mortality valuation estimates. The estimated benefits under Alternative 2 are lower than those under Alternative 3, and those under Alternative 4 are higher than those under Alternative 3 by about a factor of three.

Table E.4.3.3-4 lists BenMAP valuation results for other ozone-related health effects and associated endpoints (morbidity) for Cumulative Impacts.

Table E.4.3.3-4. BenMAP-derived Nationwide Monetized Health-related Benefits for Ozone-related Morbidity: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Various Morbidity, Cumulative Impacts

Epidemiology Study	Reduction		
	Alternative 2	**Alternative 3**	**Alternative 4**
Emergency room visits, respiratory	0	0	0
Hospital admissions, respiratory	1	1	3
School loss days (age 0–17)	1	1	2
Worker productivity loss	0	0	1
Acute respiratory symptoms (age 18–99)	1	2	5

For the endpoints considered here, the monetized health-related benefits are smallest under Alternative 2 and slightly greater for each successive action alternative. The monetized health-related benefits under the Preferred Alternative range from less than 1 million dollars, for emergency room visits for respiratory symptoms and worker productivity loss, to 2 million dollars for acute respiratory symptoms.

E.4.3.3.2 PM$_{2.5}$

Table E.4.3.3-5 lists BenMAP results for PM$_{2.5}$ mortality under the three action alternatives for Cumulative Impacts.

Table E.4.3.3-5. BenMAP Aggregated/Pooled Incidence Results for PM$_{2.5}$-related Mortality: Estimated Nationwide Reduction in Premature Mortality, Cumulative Impacts

	Reduction in Number of Cases		
	Alternative 2	**Alternative 3**	**Alternative 4**
Epidemiology Literature			
Harvard six-city study (Laden et al.)	270	390	520
American Cancer Society (ACS) study (Pope et al.)	100	150	200
Infant mortality study (Woodruff et al.)	0	1	1
Expert Elicitation			
Expert A	290	410	550
Expert B	210	300	410
Expert C	240	340	450
Expert D	160	220	300
Expert E	360	510	690
Expert F	170	240	340
Expert G	130	180	240
Expert H	160	220	300
Expert I	220	310	430
Expert J	200	280	380
Expert K	30	46	63
Expert L	140	190	260

The results vary by study due to the use of different study populations and exposure-response relationships, and by alternative. Alternative 2 is associated with the fewest reductions in mortality incidence and Alternative 4 is associated with the most reductions. Under the Preferred Alternative, the reduction in adult mortality incidence due to the simulated change in $PM_{2.5}$ concentration ranges from 150 to 390 cases for the epidemiology studies and from 46 to 510 for the expert elicitation studies.

Table E.4.3.3-6 lists BenMAP results for other $PM_{2.5}$-related health effects and associated endpoints (morbidity) for Cumulative Impacts.

Table E.4.3.3-6. BenMAP Aggregated/Pooled Incidence Results for $PM_{2.5}$-related Morbidity: Estimated Nationwide Reduction in Various Morbidity, Cumulative Impacts

	Reduction in Number of Cases		
Epidemiology Study	**Alternative 2**	**Alternative 3**	**Alternative 4**
Chronic bronchitis (age >=27)	75	100	140
Emergency room visits for asthma (age <17)	76	100	150
Acute bronchitis (age 8–12)	170	230	320
Asthma exacerbation (age 6–18)	3,500	4,900	6,600
Lower respiratory symptoms (age 7–14)	2,100	3,000	4,000
Upper respiratory symptoms (age 9–11)	1,600	2,300	3,100
Minor restricted-activity days (age 18–64)	81,000	110,000	150,000
Work loss days (age 18–64)	14,000	19,000	26,000
Nonfatal myocardial infarction (age >17)	130	180	240
Hospital admissions - respiratory (all ages)	20	29	39
Hospital admissions - cardiovascular (age >17)	47	66	90

For all endpoints considered here, the fewest reductions are associated with Alternative 2 and the most reductions are associated with Alternative 4. Under the Preferred Alternative, emergency room visits for asthma are reduced by 100 cases and hospital admissions for respiratory problems are reduced by 29 cases due to the change in simulated $PM_{2.5}$ concentration.

Table E.4.3.3-7 list BenMAP valuation results for $PM_{2.5}$-related mortality under the three action alternatives for Cumulative Impacts with a 3 percent discount rate. The monetized health-related benefits represent nationwide changes in millions of U.S. 2010-equivalent dollars.

The monetized health-related benefits under the Preferred Alternative range from 1.3 to 3.4 billion dollars for premature mortality (not including infant mortality) based on epidemiological studies (Pope et al. 2002 and Laden et al. 2006 in Abt Associates) and from 410 million to 4.5 billion dollars for the expert elicitation estimates. The monetized health-related benefits are lowest under Alternative 2. The estimated benefits under Alternative 2 are lower than those under Alternative 3, and those under Alternative 4 are higher than those under Alternative 3 by about 35 percent.

Table E.4.3.3-8 lists BenMAP valuation results for $PM_{2.5}$-related mortality for Cumulative Impacts with a 7 percent discount rate.

With the 7 percent discount, the monetized health-related benefits under the Preferred Alternative range from 1.2 to 3.1 billion dollars for premature mortality (not including infant mortality) based on epidemiological studies (Pope et al. 2002 and Laden et al. 2006 in Abt Associates) and from 370 million to 4.1 billion dollars for the expert elicitation estimates.

Table E.4.3.3-7. BenMAP Monetized Health-related Benefits for $PM_{2.5}$-related Mortality with a 3 Percent Discount Rate: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Cumulative Impacts

	Reduction		
	Alternative 2	**Alternative 3**	**Alternative 4**
Epidemiology Literature			
Harvard six-city study (Laden et al.)	2,400	3,400	4,600
ACS study (Pope et al.)	940	1,300	1,800
Infant mortality study (Woodruff et al.)	3	5	6
Expert Elicitation			
Expert A	2,600	3,600	4,900
Expert B	1,900	2,600	3,600
Expert C	2,100	3,000	4,000
Expert D	1,400	2,000	2,700
Expert E	3,200	4,500	6,200
Expert F	1,500	2,100	3,000
Expert G	1,100	1,600	2,200
Expert H	1,400	2,000	2,600
Expert I	2,000	2,800	3,800
Expert J	1,800	2,500	3,400
Expert K	290	410	560
Expert L	1,200	1,700	2,300

Table E.4.3.3-8. BenMAP Monetized Health-related Benefits for $PM_{2.5}$-related Mortality with a 7 Percent Discount Rate: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Premature Mortality, Cumulative Impacts

	Reduction		
	Alternative 2	**Alternative 3**	**Alternative 4**
Epidemiology Literature			
Harvard six-city study (Laden et al.)	2,200	3,100	4,100
ACS study (Pope et al.)	850	1,200	1,600
Infant mortality study (Woodruff et al.)	3	4	6
Expert Elicitation			
Expert A	2,300	3,200	4,400
Expert B	1,700	2,400	3,300
Expert C	1,900	2,700	3,600
Expert D	1,300	1,800	2,400
Expert E	2,900	4,100	5,500
Expert F	1,400	1,900	2,700
Expert G	1,000	1,400	1,900
Expert H	1,300	1,800	2,400
Expert I	1,800	2,500	3,400
Expert J	1,600	2,200	3,000
Expert K	260	370	500
Expert L	1,100	1,500	2,100

Table E.4.3.3-9 lists BenMAP valuation results for other $PM_{2.5}$-related health effects and associated endpoints (morbidity) for Cumulative Impacts.

Table E.4.3.3-9. BenMAP-derived Nationwide Monetized Health-related Benefits for $PM_{2.5}$-related Morbidity: Estimated Monetized Benefits (millions 2010 U.S. dollars/year) Related to Various Morbidity Endpoints, Cumulative Impacts

Epidemiology Study	Reduction		
	Alternative 2	Alternative 3	Alternative 4
Chronic bronchitis (age >=27)	41	57	78
Emergency room visits for asthma (age <17)	0	0	0
Acute bronchitis (age 8–12)	0	0	0
Asthma exacerbation (age 6–18)	0	0	0
Lower respiratory symptoms (age 7–14)	0	0	0
Upper respiratory symptoms (age 9–11)	0	0	0
Minor restricted-activity days (age 18–64)	6	8	11
Work loss days (age 18–64)	2	3	4
Nonfatal myocardial infarction (age >17)	14	20	27
Hospital admissions - respiratory (all ages)	0	0	1
Hospital admissions - cardiovascular (age >17)	1	1	1

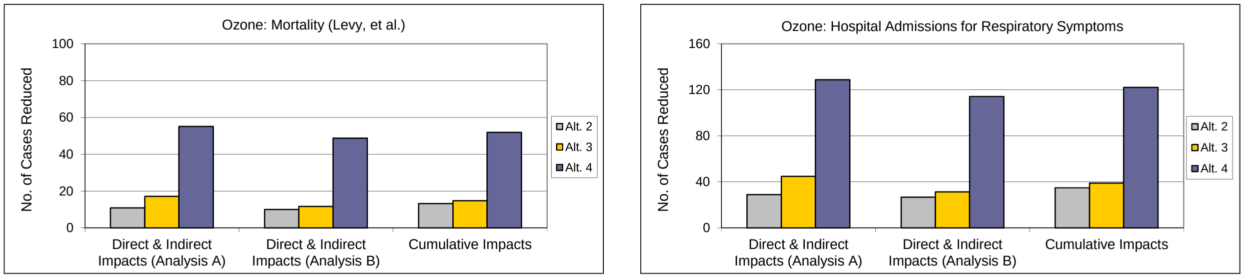
For the endpoints considered here, the monetized health-related benefits are smallest under Alternative 2 and slightly greater for each successive action alternative. The greatest reductions in monetized health-related benefits are associated with fewer incidences of chronic bronchitis and non-fatal myocardial infarctions.

E.4.3.4 Summary of BenMAP Results

One of the goals of this application was to compare the health effects and monetized health-related benefits across the range of alternatives under Analysis A, Analysis B, and Cumulative Impacts. Figures E.4.3.4-1a and b graphically display the nationwide reduction in the number of cases associated with selected health endpoints for ozone and $PM_{2.5}$. For ozone, the endpoints are mortality (Levy et al. 2005 in Abt Associates 2008), hospital admissions for respiratory symptoms, emergency room visits for respiratory symptoms, and minor restricted-activity days. For $PM_{2.5}$, the endpoints are mortality (Laden et al. 2006 in Abt Associates 2008), hospital admissions for respiratory symptoms, asthma exacerbation, and minor restricted-activity days. Note that the scales are different for each plot.

Figure E.4.3.4-1a. BenMAP-derived Changes in Selected Health Outcomes for the Direct and Indirect Impacts and Cumulative Impacts Analyses: Ozone

(a) Mortality *(b) Hospital Admissions for Respiratory Symptoms*



(c) Emergency Room Visits for Respiratory Symptoms *(d) Minor Restricted-Activity Days*

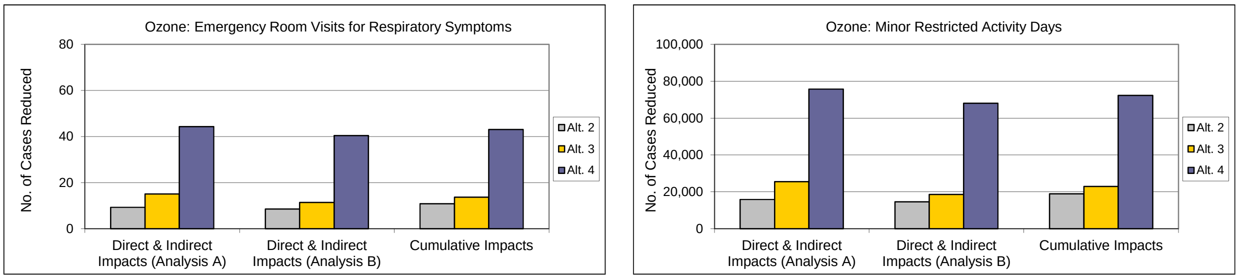
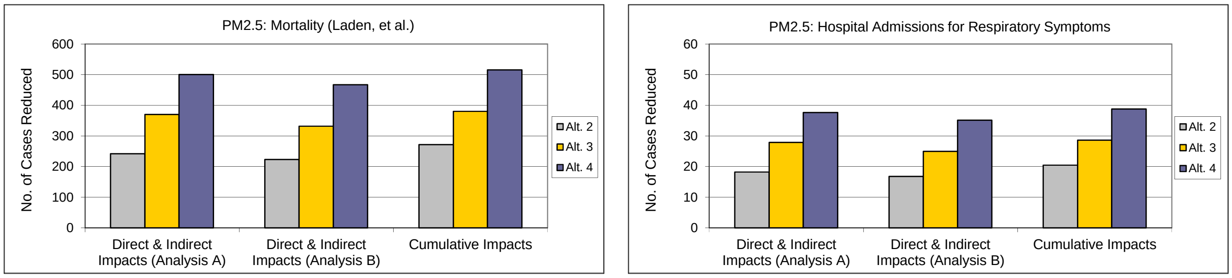
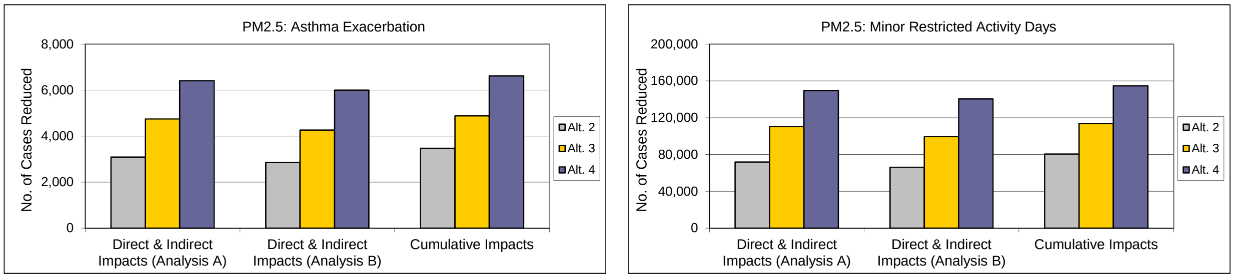


Figure E.4.3.4-1b. BenMAP-derived Changes in Selected Health Outcomes for the Direct and Indirect Impacts and Cumulative Impacts Analyses: $PM_{2.5}$

(a) Mortality *(b) Hospital Admissions for Respiratory Symptoms*



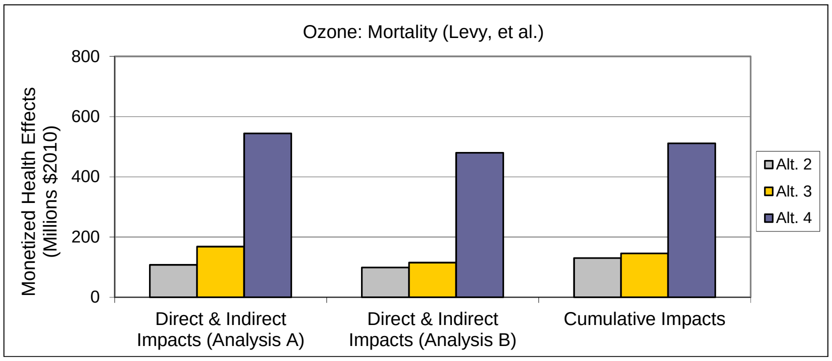
(c) Asthma Exacerbation *(d) Minor Restricted-Activity Days*



Figures E.4.3.4-2a and b graphically display the nationwide monetized health-related benefits associated with selected health endpoints for ozone and $PM_{2.5}$. For both ozone and $PM_{2.5}$, the monetized health-related benefits are displayed for mortality and combined respiratory symptoms. For ozone, the combined symptoms include emergency room visits for respiratory symptoms, hospital admissions for respiratory symptoms, and acute respiratory symptoms. For $PM_{2.5}$, the combined symptoms include chronic bronchitis, acute bronchitis, asthma exacerbation, emergency room visits for asthma, lower and upper respiratory symptoms, and hospital admissions for respiratory symptoms. Again, to accommodate differences in the results, the scales are different for each plot.

Figure E.4.3.4-2a. BenMAP-derived Monetized Health-related Benefits for the Direct and Indirect Impacts and Cumulative Impacts Analyses: Ozone

Mortality



Combined Respiratory Symptoms

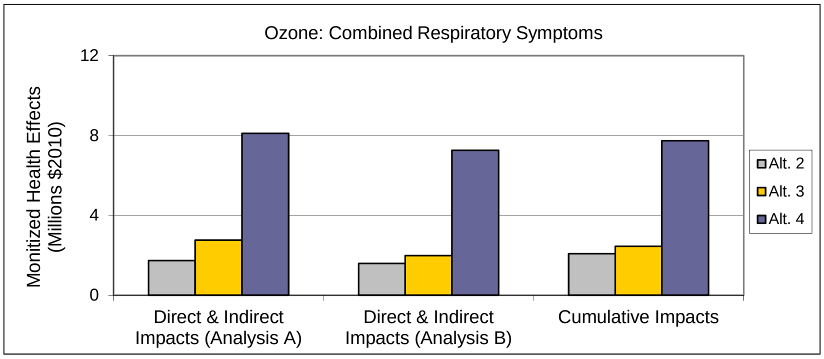
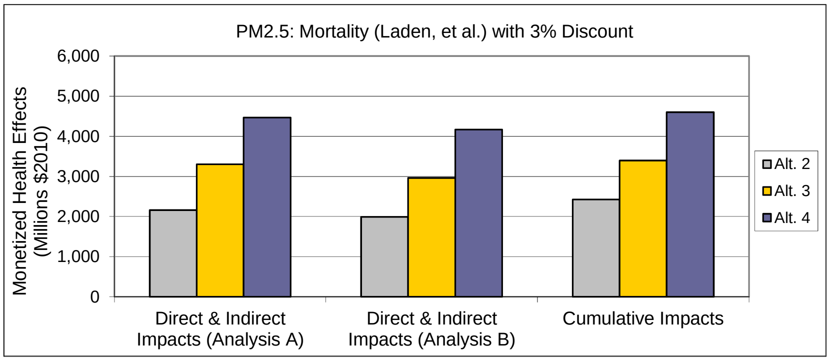
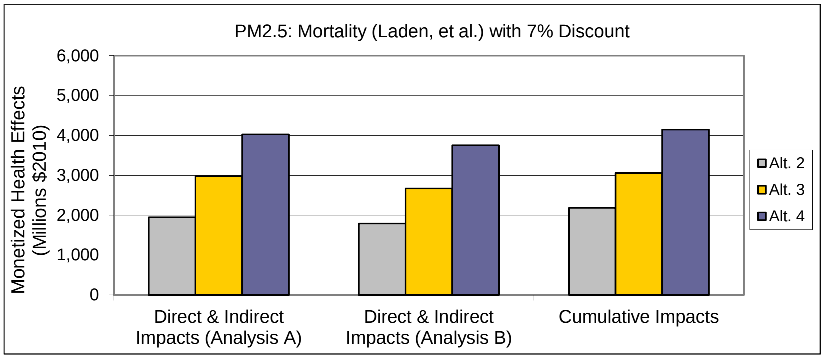


Figure E.4.3.4-2b. BenMAP-derived Monetized Health-related Benefits for the Direct and Indirect Impacts and Cumulative Impacts Analyses: PM$_{2.5}$

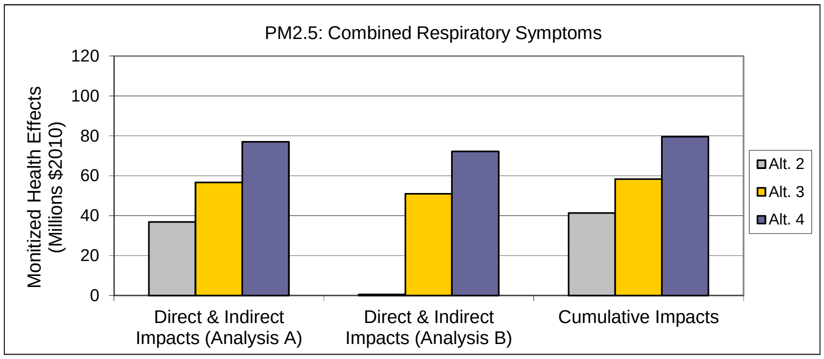
Mortality with 3 Percent Discount



Mortality with 7 Percent Discount



Combined Respiratory Symptoms



In summary:

- For all three analyses, the relative changes in health effects incidences and monetized health-related benefits among the action alternatives are consistent with the changes in emissions for the action alternatives. Because they are driven by the CMAQ modeling results, the BenMAP results are also affected by the emission changes, their spatial distributions in relation to population, and the complex (and often non-linear) chemical reactions in the atmosphere throughout each of the different regions.
- Alternative 2 (the least stringent alternative) is associated with the fewest reductions in cases of health effects and the lowest monetized health-related benefits. Alternative 4 (the most stringent alternative) is associated with the most reductions in the number of cases of health effects and the greatest monetized health-related benefits.
- Similar to other studies, the estimated health-related benefits associated with mortality are much greater than those associated with the morbidity endpoints, and the health-related benefits associated with $PM_{2.5}$ are greater than those associated with ozone.

E.4.3.5 Discussion of Attributes and Limitations

The BenMAP tool incorporates a wide variety of studies that can be used to quantify and monetize health effects. The epidemiological studies address a variety of different health endpoints and, in some cases, multiple studies (involving different populations or concentration-response functions) are available, allowing for some comparison. BenMAP includes up-to-date valuation methods and data for the monetization of health impacts. BenMAP also incorporates advanced statistical methods for aggregating and weighting the results to obtain both mean values and information about the likelihood (probability) that the value will be within a given range. A primary advantage of BenMAP is that it can incorporate the change in air quality directly from air quality model output files. Therefore, BenMAP accounts for spatial and temporal differences in the changes in air quality and relates these to population. For this analysis, selection of the health effects studies and valuation methods were based on the latest BenMAP (configuration and aggregation, pooling and valuation) input files (which reference the studies and methods EPA considers to be the most relevant and applicable to the United States population as a whole).

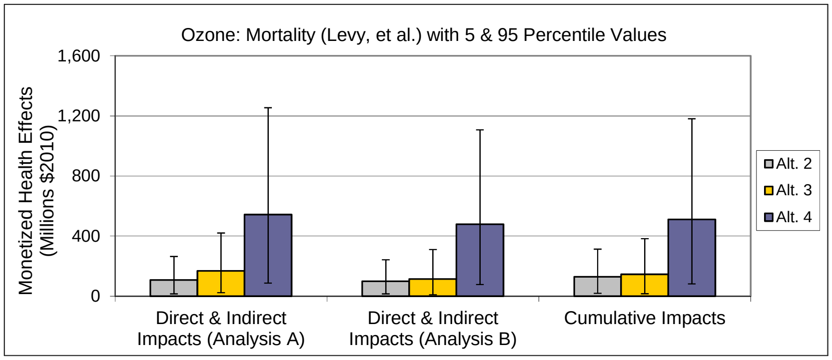
Nevertheless, there are uncertainties associated with the estimation of changes in health effects and monetized health-related benefits associated with changes in ozone and $PM_{2.5}$ air quality. For the health incidence calculations, BenMAP includes an option to generate an average incidence estimate, and range of results that assume there is variability in the inputs to the health impact functions. Variability is incorporated into most of the BenMAP exposure-response algorithms by prescribing a dose-response parameter that assumes a Gaussian (bell-shaped) distribution about the mean value. In calculating the health effects, BenMAP samples this distribution to develop a probability distribution of effect. The result is expressed as the mean value of the distribution. For the $PM_{2.5}$ mortality expert elicitation functions, variability is accounted for in a variety of ways.

For the valuation calculation, the valuation function is also specified as a probability distribution, accounting for different methods of estimating health costs and WTP. BenMAP samples from probability distributions from single or multiple cost estimation models, and combines the results through Monte Carlo simulation. The valuation function for morbidity used for this analysis is a Weibull distribution with a mean of $6.3 million (in 2000 dollars).

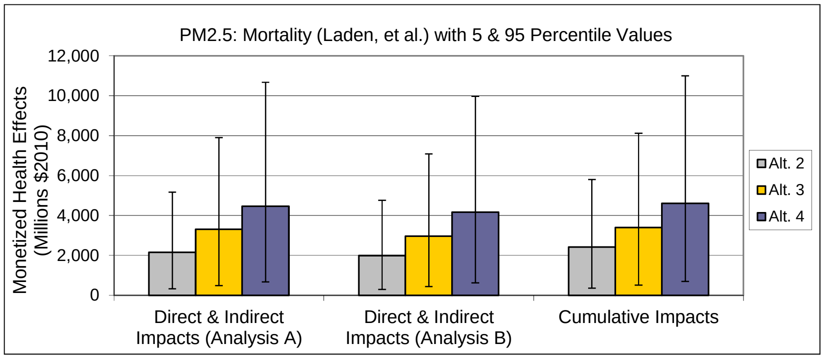
Therefore, the resulting monetized benefit distributions include contributions both from the uncertainty in the exposure-response relationships and in the valuation functions. Sections E.4.3.1 through E.4.3.4 present the expected value (mean) estimates generated by BenMAP. Figures E.3.5-1 (a)-(c) present the BenMAP-generated overall distributions in monetized health-related benefits (represented by 5th- and 95th- percentile intervals) for mortality for both ozone, as determined by Levy et al. (2005) in Abt Associates (2008), and $PM_{2.5}$, as determined by Laden et al. (2006) in Abt Associates (2008). Mortality is used here to illustrate the uncertainty because most quantified and monetized health-related benefits are associated with mortality.

Figure E.4.3.5-1. BenMAP-derived Monetized Health-related Benefits for the Direct and Indirect Impacts and Cumulative Impact Analyses, with 5th- and 95th-percentile Ranges

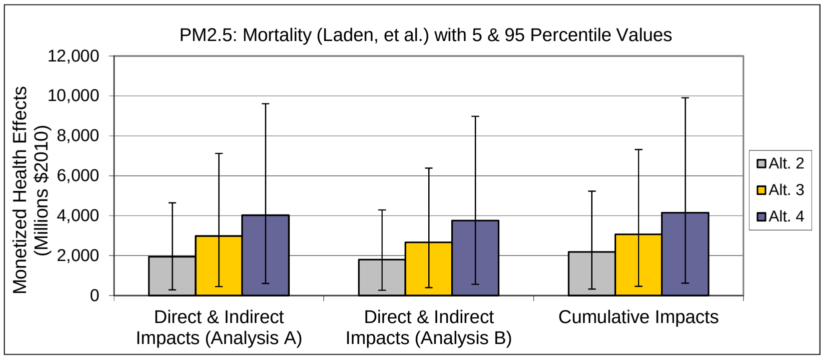
(a) Ozone Mortality



(b) PM$_{2.5}$ Mortality with 3 Percent Discount



(c) PM$_{2.5}$ Mortality with 7 Percent Discount

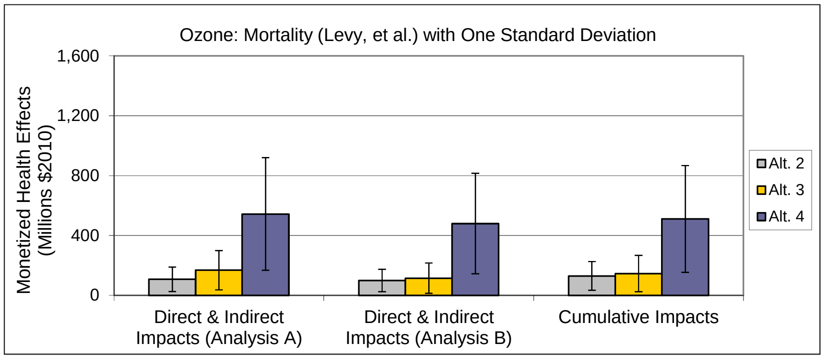


In general, the 5th- and 95th-percentile values indicate a large range in values compared to the mean value. For example, for Analysis A, the results under Alternative 2 for PM$_{2.5}$ with a 7 percent discount rate indicate that the mean value is $1.9 billion. The 5th- and 95th-percentile values are 290 million and 4.6 billion dollars, respectively. Therefore, there is a 90 percent probability that the monetized health-related benefits would be between $290 million and $4.6 billion.

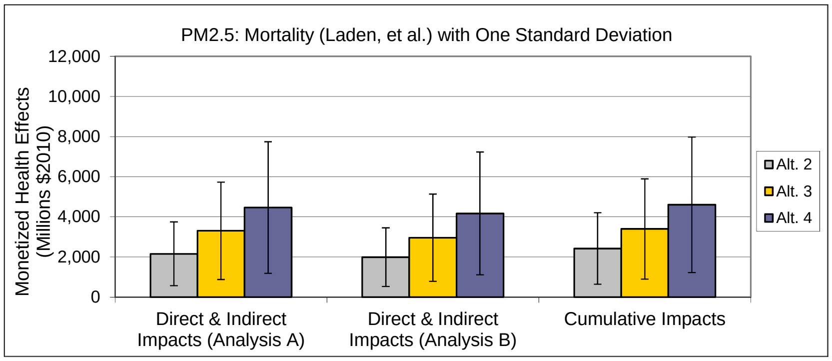
Figures E.4.3.5-2 (a)-(c) present the BenMAP-generated mean and standard deviations in monetized health-related benefits for mortality for both ozone, as determined by Levy et al. (2005) in Abt Associates (2008), and $PM_{2.5}$, as determined by Laden et al. (2006) in Abt Associates (2008).

Figure E.4.3.5-2. BenMAP-derived Monetized Health-related Benefits for the Direct and Indirect Impacts and Cumulative Impact Analyses, with One Standard Deviation

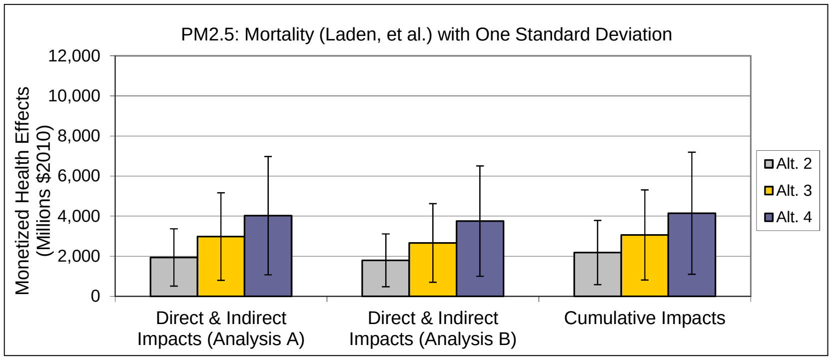
(a) Ozone Mortality



(b) $PM_{2.5}$ Mortality with 3 Percent Discount



(c) $PM_{2.5}$ Mortality with 7 Percent Discount



The standard deviation values indicate considerable variability in the distributions, leading to uncertainty in the results. For example, for Analysis A, the results under Alternative 2 for $PM_{2.5}$ with a 7 percent discount rate indicate that the mean value is 1.9 billion dollars and the standard deviation is 1.4 billion.

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E.5.2 Preparers

Sharon G. Douglas, Senior Manager, ICF International
M.S., Meteorology, Pennsylvania State University, University Park, PA, 1986
B.A., Earth and Planetary Science, Johns Hopkins University, Baltimore, MD, 1983

Jay L. Haney, Technical Director, ICF International
M.S., Meteorology, Saint Louis University, St. Louis, Missouri, 1980
B.S., Meteorology, Saint Louis University, St. Louis, Missouri, 1978

Belle Hudischewskyj Guelden, Senior Associate, ICF International
B.S., Meteorology, California State University, San Jose, 1980
A.S., Mathematics, Sierra Junior College, 1977

Thomas C. Myers, Senior Technical Specialist, ICF International
M.A., Physics, University of California at Davis, 1976
B.S., Physics, University of the Pacific, 1971

Yihua Wei, Senior Associate, ICF International
M.S., Atmospheric Science, State University of New York at Albany, 1988
M.S., Physics, Indiana State University, 1986
B.S., Physics, Nanjing University, China, 1982