Corporate Average Fuel Economy Standards

Passenger Cars and Light Trucks

Model Years 2017-2025

Draft Environmental Impact Statement

November 2011

Docket No. NHTSA-2011-0056

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Draft Environmental Impact Statement
Corporate Average Fuel Economy Standards
Passenger Cars and Light Trucks
Model Years 2017-2025

RESPONSIBLE AGENCY:

National Highway Traffic Safety Administration (NHTSA)

COOPERATING AGENCY:

U.S. Environmental Protection Agency (EPA)

TITLE:

Draft Environmental Impact Statement, Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2017-2025

ABSTRACT:

This Draft Environmental Impact Statement (Draft EIS) analyzes the environmental impacts of fuel economy standards and reasonable alternative standards for model years 2017-2025 passenger cars and light trucks ("light-duty vehicles") that NHTSA has proposed under the Energy Policy and Conservation Act, as amended. Environmental impacts analyzed in this Draft EIS include those related to fuel and energy use, air quality, and climate change. In developing the proposed Corporate Average Fuel Economy (CAFE) standards, NHTSA considered "technological feasibility, economic practicability, the effect of other vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy" as required by 49 U.S.C. § 32902(f). The proposal is consistent with President Obama's directive to improve the fuel economy of and reduce greenhouse gas emissions from model year 2017-2025 light-duty vehicles through coordinated Federal standards.

PUBLIC COMMENT PERIOD:

Comments to this Draft EIS must be received no later than January 31, 2012. To submit comments electronically, go to http://www.regulations.gov and follow the online instructions for submitting comments. File comments in Docket No. NHTSA-2011-0056. If sending by mail, send an original and two copies of your comments to: Docket Management Facility, M-30, U.S. Department of Transportation, West Building, Ground Floor, Room W12-140, 1200 New Jersey Avenue, SE, Washington, DC 20590. Please be sure to reference Docket No. NHTSA-2011-0056. Comments may also be submitted by fax to: 202-493-2251. Information about public hearings will be available at http://www.nhtsa.gov/fuel-economy and in an upcoming *Federal Register* notice.

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DRAFT ENVIRONMENTAL IMPACT STATEMENT

CORPORATE AVERAGE FUEL ECONOMY STANDARDS
PASSENGER CARS AND LIGHT TRUCKS
MODEL YEARS 2017-2025

NOVEMBER 2011

LEAD AGENCY:
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

COOPERATING AGENCY:
U.S. ENVIRONMENTAL PROTECTION AGENCY

Table of Contents

Appendices

List of Tables

List of Figures

ACRONYMS AND ABBREVIATIONS

This list of acronyms and abbreviations defines those used in the text of the main document. Table footnotes define acronyms and abbreviations used therein. Acronyms and abbreviations in figures are defined within the figures or just below them.

°C	degrees Celsius
°F	degrees Fahrenheit
$\mu g/m^3$	micrograms per cubic meter
AEO	Annual Energy Outlook
AER	Annual Energy Review
AMO	Atlantic Multidecadal Oscillation
AMOC	Atlantic Meridional Overturning Circulation
AOGCM	atmospheric-ocean general circulation model
BACT	Best Available Control Technology
BTU	British thermal unit
CAA	Clean Air Act
CAFE	Corporate Average Fuel Economy
CBD	Center for Biological Diversity
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CH_4	methane
CMAQ	Congestion Mitigation and Air Quality Improvement
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CRC	Consulting Resources Corporation
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DPM	diesel particulate matter
EDF	Environmental Defense Fund
EIA	Energy Information Administration
EIS	Environmental Impact Statement
EISA	Energy Independence and Security Act
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPCA	Energy Policy and Conservation Act
EV	electric vehicle
FHWA	Federal Highway Administration
FR	Federal Register
FTA	Federal Transit Administration
GCAM	Global Change Assessment Model
GCM	general circulation model
GDP	gross domestic product
GHG	greenhouse gas

GIS	geographic information system
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GWP	global warming potential
HD	heavy-duty; medium- and heavy-duty
HEV	hybrid electric vehicle
HFC	hydrofluorocarbon
HHS	U.S. Department of Health and Human Services
IARC	International Agency for Research on Cancer
IEO	International Energy Outlook
IGSM	Integrated Global System Model
IPCC	Intergovernmental Panel on Climate Change
IRIS	Integrated Risk Information System
ICCT	International Council on Clean Transportation
ISO	International Organization for Standardization
LCA	life-cycle assessment
Li-ion	Lithium-ion
MAGICC	Model for Assessment of Greenhouse Gas-induced Climate Change
MERGE	Model for Evaluating Regional and Global Effects
MDOT	Michigan Department of Transportation
$MMTCO_2$	million metric tons of carbon dioxide
$MMTCO_2e$	million metric tons of carbon dioxide equivalent
MOC	Meridional Overturning Circulation
MOVES	Motor Vehicle Emission Simulator (EPA)
MOVES2010	2010 Motor Vehicle Emission Simulator (EPA)
mpg	mile per gallon
mph	mile per hour
MSAT	mobile source air toxic
MY	model year
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NHTSA	National Highway Traffic Safety Administration
NO	nitric oxide
NO_2	nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxides
NPRM	Notice of Proposed Rulemaking
NRC	National Research Council
NRDC	Natural Resources Defense Council
NVH	noise, vibration, and harshness
PAH	polycyclic aromatic hydrocarbon
PETM	Paleocene-Eocene thermal maximum
PFC	perfluorocarbon

PHEV	plug-in hybrid electric vehicle
POM	polycyclic organic matter
PM	particulate matter
PM_{10}	particulate matter, 10 microns diameter or less
$PM_{2.5}$	particulate matter, 2.5 microns diameter or less
ppm	parts per million
PSD	Prevention of Significant Deterioration
RCP	Representative Concentration Pathway
RFS	Renewable Fuel Standard
RFS2	Renewable Fuel Standard 2
RGGI	Regional Greenhouse Gas Initiative
RIA	Regulatory Impact Analysis
SAP	Synthesis and Assessment Product
SCC	social cost of carbon
SF_6	sulfur hexafluoride
SIP	State Implementation Plan
SO_x	sulfur oxides
SO_2	sulfur dioxide
SRES	Special Report on Emission Scenarios
TS&D	Transportation, Storage, and Distribution
TSD	Technical Support Document
UCS	Union of Concerned Scientists
U.S.C.	United States Code
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
VMT	vehicle miles traveled
VOC	volatile organic compound
VSL	value of statistical life
WCI	Western Climate Initiative
WGI	Work Group I, IPCC
WMO	World Meteorological Organization

Glossary

To help readers more fully understand this EIS, this Glossary includes definitions for technical and scientific terms, and plain English terms used differently in the context of the EIS. Italicized terms in definitions indicate terms also included in this Glossary.

Term	Definition
Adaptation	As used in this EIS, initiatives and measures to reduce the vulnerability of natural and human systems from actual or expected effects of climate change effects. There are various types of adaptation, including anticipatory and reactive, private and public, and autonomous and planned.
Albedo	Surfaces on Earth reflect solar radiation back to space. The reflective characteristic, known as albedo, indicates the proportion of incoming solar radiation that the surface reflects. High albedo has a cooling effect because the surface reflects rather than absorbs most solar radiation.
Anthropogenic	Resulting from or produced by humans.
Attainment area	Region where concentrations of *criteria pollutants* do not exceed limits established under National Ambient Air Quality Standards.
Battery electric vehicle (BEV)	Type of *electric vehicle* that is completely electrically powered and does not incorporate an internal combustion engine.
Benthic	Describing habitat or organisms occurring at the bottom of a body of water.
Biofuel	Liquid fuels and blending components produced from biomass feedstocks, used primarily for transportation
Biomass	Organic non-fossil material of biological origin (material from living, or recently living organisms) constituting a renewable energy source.. As an energy source, biomass can either be used directly, or converted into other energy products such as *biofuel*. Direct biomass fuel can be used to generate electricity with steam turbines and gasifiers or produce heat, usually by direct combustion. Examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. Converted biomass includes plant or animal matter converted into fibers or other industrial chemicals, including biofuels. Biomass can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, and a variety of tree species, ranging from eucalyptus to oil palm (palm oil).
Biosphere	The part of the Earth system comprising all ecosystems and living organisms, in the atmosphere, on land (terrestrial biosphere), or in the oceans (marine biosphere).

Term	Definition
Black carbon	Operationally defined aerosol species based on measurement of light absorption and chemical reactivity and/or thermal stability; consists of soot, charcoal, and/or possible light-absorbing refractory organic matter.
Carbon fixation	This is the process by which inorganic carbon (typically CO_2) is used in an organic compound. An example is the uptake of CO_2 by plants during the process of photosynthesis.
Carbon sequestration	The act or process of increasing carbon storage of a reservoir (other than the atmosphere).
Carbon sink	Any process, activity, or mechanism that removes a *greenhouse gas*, an aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere.
Climate feedback	An interaction mechanism between processes in the climate system is called a climate feedback, when the result of an initial process triggers changes in a second process that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it
Criteria pollutants	Air pollutants for which EPA has established National Ambient Air Quality Standards. Under the Clean Air Act, as amended, EPA has established National Ambient Air Quality Standards for six relatively commonplace pollutants (carbon monoxide, airborne lead, nitrogen dioxide, ozone, sulfur dioxide, and fine particulate matter; these are the *criteria pollutants*) that can accumulate in the atmosphere as a result of normal levels of human activity.
Cryosphere	The portion of Earth's surface frozen water, such as snow, *permafrost*, floating ice, and glaciers.
Cumulative impacts	"…the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions." 40 CFR § 1508.7
Direct impacts	Effects "caused by the action and occur at the same time and place." 40 CFR § 1508.8.
Downstream emissions	Emissions released from a vehicle while it is in operation, parked, or being refueled, and consisting of tailpipe exhaust, evaporative emissions of volatile organic compounds from the vehicle's fuel storage and delivery system, and particulates generated by brake and tire wear.
Ecosystem	A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Therefore, the extent of an ecosystem can range from very small spatial scales to, ultimately, all of Earth.

Term	Definition
Electric vehicle (EV)	A vehicle that uses battery technologies to provide power, therefore reducing or even eliminating liquid fuel consumption during vehicle operation. The term "electric vehicle" covers a range of different vehicle types, including battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs).
El Niño-Southern Oscillation (ENSO)	The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with a basin-wide warming of the tropical Pacific east of the international dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, with preferred time scales of 2 to about approximately 7 years, is collectively known as El Niño-Southern Oscillation, or ENSO. During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the sea surface temperatures warm, further weakening the trade winds.
Emission rate	Rate at which contaminants are discharged from a particular source, usually in weight unit per time period.
Energy intensity	The sum of all energy supplied to an economy divided by its real (inflation-adjusted) *Gross Domestic Product*. Energy intensity measures the efficiency at which energy is converted to GDP; a high value indicates an inefficient conversion of energy to GDP and a lower value indicates a more efficient conversion.
Eutrophication	The process by which a body of water (often shallow) becomes rich in dissolved nutrients, like phosphorus and nitrogen. Sources for these nutrients typically include agricultural fertilizers and sewage.
Evapotranspiration	The combined process of water evaporation from Earth's surface and *transpiration* from vegetation.
Fossil fuel	Fuels formed by natural processes such as anaerobic (in the absence of oxygen) decomposition of buried dead organisms. The age of the organisms resulting in fossil fuels is typically millions of years, and sometimes exceeds 650 million years. Fossil fuels, which contain carbon, include coal, petroleum, and natural gas.
Global warming potential (GWP)	A relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of CO_2. GWP is calculated over a specific time interval, commonly 20, 100, or 500 years. GWP is expressed as a factor of CO_2 (whose GWP is standardized to 1). For example, the 100-year GWP of methane according to IPCC's Second Assessment Report is 21, which means that if the same mass of methane and CO_2 were introduced into the atmosphere, that methane will trap 21 times more heat than the CO_2 over the next 100 years.

Term	Definition
Greenhouse gas (GHG)	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the greenhouse effect. Water vapor (H_2O), CO_2, nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances.
GREET model	Model developed by Argonne National Laboratory that provides estimates of energy use and emissions associated with vehicle and fuel systems. GREET calculates consumption of total energy, fossil fuels, petroleum, coal and natural gas, emissions of CO_2-equivalent greenhouse gases, and emissions of criteria pollutants. GREET is used in this EIS analysis to model *upstream emissions*.
Gross Domestic Product (GDP)	The total market value of all the goods and services produced in an economy at a given time.
Hybrid electric vehicle (HEV)	Type of *electric vehicle* that incorporates a battery and electric motor system coupled with an internal combustion engine.
Hydrosphere	The component of the climate system comprising liquid surface and subterranean water, such as oceans, seas, rivers, freshwater lakes, and underground water.
Indirect impacts	Effects that "are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable." 40 CFR § 1508.8.
Life-cycle assessment (LCA)	An analytical method based on a systems perspective used to evaluate the environmental impacts of materials, products, processes, or systems throughout their life cycles.
Mass reduction	Mass reduction reduces fuel consumption by decreasing vehicle mass while maintaining the same vehicle size.
MOVES model	The Motor Vehicle Emission Simulator (MOVES), developed by EPA's Office of Transportation and Air Quality, is a modeling system that estimates emissions of *criteria pollutants* and *toxic air pollutants* for on-road mobile sources. MOVES currently estimates emissions from cars, trucks and motorcycles, and is used in this EIS analysis to model *downstream emissions*.
NEPA scoping process	An early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action.

Term	Definition
Nonattainment area	Region where concentrations of *criteria pollutants* exceed federal limits National Ambient Air Quality Standards. Nonattainment areas are required to develop and implement plans to comply with the National Ambient Air Quality Standards within specified periods.
Ocean acidification	A decrease in the pH of sea water due to the uptake of *anthropogenic* carbon dioxide.
Paleoclimatology	The study of climate change through the physical evidence left on Earth of historical global climate change (prior to the widespread availability of records to temperature, precipitation, and other data).
Permafrost	Ground (soil or rock and included ice and organic material) that remains at or below zero degrees Celsius for at least 2 consecutive years.
Phenology	The study of natural phenomena in biological systems that recur periodically (development stages, migration) and their relationship to climate and seasonal changes.
Plug-in hybrid electric vehicle (PHEV)	A hybrid vehicle with a large capacity rechargeable battery that can be recharged by plugging into the electricity grid as well as using the on-board charging capabilities of normal hybrids (e.g., regenerative braking). Just like a normal hybrid vehicle, a plug-in hybrid also utilizes an internal combustion engine as a backup when battery life is depleted.
Photosynthetic nitrogen efficiency	The amount of carbon in the plant that is converted to usable sugars during photosynthesis. With greater atmospheric CO_2, the amount of carbon converted to sugars is greater even when the amount of nitrogen is available to the plant does not change.
Phototoxicity	An abnormal adverse reaction of a plant to ultraviolet radiation during which a toxic compound in a plant can be produced or enhanced. This can be exacerbated by environmental pollutants or increasing UV radiation.
Primary fuels	Energy sources consumed in the initial production of energy. Primary fuels used in the United States include nuclear power, hydropower, coal, natural gas, and crude oil (converted to petroleum and other liquid fuels for consumption).
Radiative forcing	Measure of how a climatic factor such as a GHG affects the energy balance of the Earth-atmosphere system. A positive forcing tends to warm the Earth's surface while a negative forcing tends to cool it.
Rebound effect	A situation in which improved fuel economy reduces the fuel cost of driving and leads to additional use of passenger cars and light trucks.
Quads	In this EIS, quadrillion British thermal units.

Term	Definition
Social cost of carbon (SCC)	An estimate of the monetized climate-related damages associated with an incremental increase in annual carbon emissions; the estimated price of the damages caused by each ton of CO_2 released into the atmosphere. In cost-benefit analysis of government regulations, the higher the SCC, the more stringent the standards. For example, if the price of the damages caused by each ton of CO_2 released into the atmosphere were $10, only regulations that cost less than $10 to implement would be deemed worthwhile. The higher the cost of damages caused by each ton of CO_2 released into the atmosphere, the greater the demands imposed on polluters
Survival rate	In the context of this EIS, the proportion of vehicles originally produced during a model year that are expected to remain in service at the age they will have reached during each subsequent year.
Stratification	The layering of warmer, less dense water over colder, denser water.
Technologies	In the context of this EIS, engine technologies, transmission, vehicle, electrification/accessory, and hybrid technologies that influence fuel economy.
Tipping point	A situation where the climate system reaches a point at which is there is a strong and amplifying *positive feedback* from only a moderate additional change in a driver, such as CO_2 or temperature increase.
Toxic air pollutants	Toxic air pollutants, also known as hazardous air pollutants, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. EPA has identified 188 substances as toxic air pollutants.
Track width	The lateral distance between the centerlines of the base tires at ground.
Transpiration	Water loss from plant leaves.
Upstream emissions	Emissions associated with crude-petroleum extraction and transportation, and with the refining, storage, and distribution of transportation fuels.
Urban Heat island effect	Phenomenon of consistently higher ambient temperatures in metropolitan regions compared to the surrounding rural areas. Metropolitan regions have modified the land surfaces with materials (e.g., pavement) that absorb solar energy, thereby retaining heat within the localized area.
Vehicle footprint	A vehicle's wheelbase multiplied by the vehicle's average track width.
Vehicle miles traveled (VMT)	Total number of miles driven.

Term	Definition
Volpe model	CAFE compliance and effects model developed by the DOT Volpe Center that, for any given year, applies technologies to the manufacturer's fleet until the manufacturer achieves compliance with the standard under consideration.
Wheelbase	The longitudinal distance between front and rear wheel centerlines.

SUMMARY

FOREWORD

The National Highway Traffic Safety Administration (NHTSA) prepared this Environmental Impact Statement (EIS) to analyze and disclose the potential environmental impacts of the proposed model year (MY) 2017–2025 Corporate Average Fuel Economy (CAFE) Standards for passenger cars and light trucks (the Proposed Action). This document was prepared pursuant to Council on Environmental Quality (CEQ) National Environmental Policy Act (NEPA) implementing regulations, U.S. Department of Transportation (DOT) Order 5610.1C, and NHTSA regulations.

This EIS compares the potential environmental impacts of four alternative approaches to regulating light-duty vehicle fuel economy for MYs 2017–2025, including a Preferred Alternative (i.e., the proposed standards) and a No Action Alternative. This EIS analyzes direct, indirect, and cumulative impacts in proportion to their potential significance. The alternatives NHTSA selected for evaluation encompass a reasonable range of alternatives to evaluate the potential environmental impacts of the proposed standards and alternatives under NEPA. EIS chapters and appendices provide or reference all relevant supporting information.

BACKGROUND

The Energy Policy and Conservation Act of 1975 (EPCA) established the CAFE program to reduce national energy consumption by increasing the fuel economy of passenger cars and light trucks. EPCA directs the Secretary of Transportation to set and implement fuel economy standards for passenger cars and light trucks sold in the United States. NHTSA is delegated responsibility for implementing EPCA fuel economy requirements assigned to the Secretary. In December 2007, Congress enacted the Energy Independence and Security Act of 2007 (EISA), amending the EPCA CAFE program requirements by providing DOT additional rulemaking authority and responsibilities. Pursuant to EISA, NHTSA has issued final CAFE standards for MY 2011 passenger cars and light trucks, as well as standards for MY 2012–2016 passenger cars and light trucks and MY 2014–2018 medium- and heavy-duty vehicles in joint rulemakings with the Environmental Protection Agency (EPA).

On May 21, 2010, President Obama issued a Presidential Memorandum entitled “Improving Energy Security, American Competitiveness and Job Creation, and Environmental Protection through a Transformation of our Nation’s Fleet of Cars and Trucks.” This memorandum builds on the President’s previous memorandum from January 26, 2009, which established a Joint National Program and led to the NHTSA and EPA joint final rules establishing fuel economy and greenhouse gas (GHG) standards for MY 2012–2016 passenger cars and light trucks. The President’s 2010 memorandum requested that NHTSA and EPA continue the joint National Program by developing joint federal standards to improve fuel efficiency and reduce the GHG emissions of U.S. passenger cars and light trucks manufactured in MYs 2017–2025. The President requested that the agencies develop a Notice of Intent announcing plans for setting those standards by September 30, 2010, which would include “potential standards that could be practicably implemented nationally for the 2017–2025 model years and a schedule for setting those standards as expeditiously as possible, consistent with providing sufficient lead time to vehicle manufacturers.”

On September 30, 2010, NHTSA and EPA issued a Notice of Intent that announced plans to develop a rulemaking setting stringent fuel economy and GHG emissions standards for U.S. passenger cars and light trucks for MY 2017 and beyond. The notice was accompanied by an Interim Joint Technical Assessment Report, intended to inform the rulemaking process, which was developed by NHTSA, EPA, and the California Air Resources Board (CARB), in coordination with the U.S. Department of Energy (DOE). On December 8, 2010, the agencies published a Supplemental Notice of Intent highlighting many of the key comments received in response to the September Notice of Intent and the Interim Joint Technical Assessment Report. Over the next several months, the agencies, working with California, engaged in discussions with individual auto manufacturers, automotive suppliers, states, environmental groups, consumer groups, and the United Auto Workers, who all expressed support for a continuation of the National Program. These discussions and efforts focused on developing information that supported the underlying technical assessments that informed the proposed standards.

On May 10, 2011, NHTSA published a Notice of Intent to prepare an EIS for new CAFE standards. On July 29, 2011, NHTSA and EPA issued a final Supplemental Notice of Intent generally describing the agencies' expectations for the Notice of Proposed Rulemaking (NPRM), including the intended levels of standards to be proposed and key program elements like compliance flexibilities and the mid-term evaluation. That NPRM is being issued simultaneously with this Draft EIS.

NHTSA developed this EIS pursuant to NEPA, which directs that federal agencies proposing "major federal actions significantly affecting the quality of the human environment" must, "to the fullest extent possible," prepare "a detailed statement" on the environmental impacts of the proposed action (including alternatives to the proposed action). To inform its development of the proposed CAFE standards, NHTSA prepared this EIS, which analyzes, discloses, and compares the potential environmental impacts of a reasonable range of action alternatives, including a proposed Preferred Alternative, and discusses impacts in proportion to their significance.

PURPOSE AND NEED FOR THE PROPOSED ACTION

NEPA requires that proposed alternatives be developed based on the action's purpose and need. The purpose and need statement explains why the action is needed, describes the action's intended purpose, and serves as the basis for developing the range of alternatives to be considered in the NEPA analysis. In accordance with EPCA, as amended by EISA, one purpose of the Joint Rulemaking is to establish MY 2017–2025 CAFE standards at "the maximum feasible average fuel economy level that the Secretary of Transportation decides the manufacturers can achieve in that model year." When determining the maximum feasible levels that manufacturers can achieve in each model year, EPCA requires that the Secretary of Transportation consider the four statutory factors of technological feasibility, economic practicability, the effect of other motor vehicle standards of the government on fuel economy, and the need of the United States to conserve energy. In addition, the agency has the authority to – and traditionally does – consider other relevant factors, such as the effect of the CAFE standards on motor vehicle safety.

Under EISA, NHTSA must establish separate standards for passenger cars and light trucks for each model year, subject to two principal requirements. First, in certain years, the standards are subject to a minimum requirement regarding stringency – they must be set at levels high enough to ensure that the combined U.S. passenger car and light-truck fleet achieves an average fuel economy level of not less than 35 miles per gallon (mpg) not later than MY 2020.

Second, EPCA requires that the agency establish separate average fuel economy standards for all new passenger cars and light trucks at the maximum feasible average fuel economy level that the Secretary of Transportation decides the manufacturers can achieve in that model year.

Finally, NHTSA also is acting pursuant to President Obama's memorandum to the Department on May 21, 2010, as described in Section 1.1 of this EIS. This memorandum further outlines the purpose of and need for the Proposed Action. The NEPA analysis in this EIS informs the agency's action in setting CAFE standards for MY 2017–2025 passenger cars and light trucks.

PROPOSED ACTION AND ALTERNATIVES

NEPA requires an agency to compare the potential environmental impacts of its Proposed Action and a reasonable range of alternatives. NHTSA's Proposed Action is to set fuel economy standards for MY 2017–2025 passenger cars and light trucks in accordance with EPCA, as amended by EISA. In developing the proposed standards and alternatives, NHTSA considered the four EPCA factors that guide the agency's determination of "maximum feasible" standards. NHTSA's decisionmaking process balances the four statutory EPCA factors, along with considerations such as environmental impacts and safety.

Because in any single rulemaking under EPCA, standards may be established for not more than 5 model years, NHTSA intends to issue conditional standards for MYs 2022–2025. The CAFE standards for MYs 2022–2025 will be determined with finality in a subsequent, de novo notice and comment rulemaking conducted in full compliance with Section 32902 of Title 49 of the United States Code and other applicable law. Because these two NHTSA actions are being proposed together to increase the efficiency of the light-duty vehicle fleet, and because they are part of a joint NHTSA/EPA rulemaking for a coordinated National Program covering MYs 2017–2025, this EIS addresses the potential environmental impacts of the proposed alternatives for the full MY 2017–2025 period together, notwithstanding the provision for a mid-term evaluation.

NHTSA has selected a reasonable range of alternatives to evaluate the potential environmental impacts of the proposed CAFE standards and alternatives under NEPA. The specific alternatives NHTSA selected, described below and listed in Table S-1 and Sections 2.2.1 and 2.2.2 of this EIS, encompass a reasonable range within which to set CAFE standards and to evaluate the potential environmental impacts under NEPA, in view of EPCA requirements. Pursuant to CEQ regulations, the agency has included a No Action Alternative (Alternative 1), which assumes no action would occur under the National Program. The No Action Alternative assumes that NHTSA would not issue a rule regarding CAFE standards for MY 2017–2025 passenger cars and light trucks; rather, consistent with previous EISs, the agency assumes that NHTSA's MY 2016 fuel economy standards and EPA's MY 2016 GHG standards would continue indefinitely. This alternative provides an analytical baseline against which to compare the environmental impacts of the action alternatives.

In recognition of the uncertainty inherent in forecasting the fuel economy of the future light-duty vehicle fleet in the absence of the agencies' action, this EIS provides two analyses regarding the No Action Alternative and the corresponding impacts of action alternatives. "Analysis A" reflects a No Action Alternative that assumes that, in the absence of the Proposed Action, the baseline light-duty vehicle fleet in MYs 2017–2025 and beyond would 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 after MY 2025 under the action alternatives will never exceed the level of the MY 2025 standards. Tables and figures in this summary that depict results for Analysis A include an "A" after the table or figure number.

"Analysis B" reflects a No Action Alternative that assumes that, in the absence of the agencies' action, the average fleetwide fuel economy level of passenger cars and light trucks would continue to increase beyond the level necessary to meet the MY 2016 standards. NHTSA forecasted this fleet using the "voluntary over-compliance" simulation capability of the Volpe model, described in Section 2.2.1 of this EIS and in Section IV.C.4.c of the NPRM. For this simulation, the agency used all of the same inputs as for Analysis A, but applied a payback period of 1 year for purposes of calculating the value of future fuel savings when simulating whether a manufacturer would apply additional technology to an already CAFE-compliant fleet. For technologies applied to a manufacturer's fleet that has not yet achieved compliance with CAFE standards, the agency continued to apply a 5-year payback period. Further discussion of this methodology is available in Section IV.G of the NPRM. For the action alternatives, the agency has assumed that fleetwide fuel economy will continue to increase after MY 2025 beyond the levels necessary to meet the MY 2025 standards. Specifically, the agency assumes that the fuel economy achieved by new passenger cars and light trucks will increase at rates of 0.2 percent and 0.4 percent annually after MY 2025. These rates of increase were developed by examining historical changes in the fuel economy of new passenger cars and light trucks during periods when CAFE standards remained fixed and did not require manufacturers to offer vehicles with higher fuel economy than in the immediately preceding model years. Tables and figures in this summary that depict results for Analysis B include a "B" after the table or figure number.

Table S-1. Estimated Average Required and Achieved Fleetwide Fuel Economy (mpg) for Combined U.S. Passenger Cars and Light Trucks by Model Year and Alternative

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Required									
2 - 2%/Year Cars and Trucks	35.4	36.2	37.1	37.9	38.7	39.6	40.4	41.4	42.3
3 - Preferred	35.3	36.4	37.5	38.8	40.9	42.9	45.0	47.3	49.6
4 - 7%/Year Cars and Trucks	37.2	40.3	43.5	46.9	50.6	54.6	59.0	63.8	69.0
Achieved									
1 - No Action, Analysis A	33.4	33.8	34.1	34.4	34.5	34.6	34.7	34.8	34.9
1 - No Action, Analysis B	33.3	33.9	34.2	34.5	34.6	34.7	34.9	35.1	35.3
2 - 2%/Year Cars and Trucks	34.1	35.3	36.7	37.7	38.6	39.2	39.7	40.4	40.9
3 - Preferred	34.3	35.8	37.8	39.4	41.0	42.0	43.3	44.9	46.7
4 - 7%/Year Cars and Trucks	36.6	39.0	41.7	44.3	45.8	47.5	49.9	53.3	55.6

Table S-1 shows the estimated average required and achieved fleetwide fuel economy that NHTSA forecasts under the No Action Alternative and the action alternatives for both Analysis A and Analysis B by model year during the regulatory period. Because Analysis A and Analysis B differ only in relation to fuel economy gains under the No Action Alternative and after 2025, the estimated achieved fuel economy levels under the action alternatives for the regulatory period (MYs 2017–2025) are essentially the same for both analyses.

NHTSA has analyzed a range of action alternatives with stringencies that increase annually on average 2 percent to 7 percent from the MY 2016 standards for passenger cars and for light trucks. As NHTSA stated in the Notice of Intent to issue an EIS, the agency believes that, based on the different ways it could weigh EPCA's four statutory factors, the maximum feasible level of CAFE stringency falls within this range. Throughout this EIS, estimated impacts are shown for three action alternatives that illustrate this range of average annual percentage increases. Table S-1 shows the estimated average required and achieved fleetwide fuel economy NHTSA forecasts by model year under the three action alternatives. These action alternatives are as follows:

- Alternative 2 – Alternative 2 would require a 2 percent average annual fleetwide increase in mpg for both passenger cars and light trucks for MYs 2017–2025. Alternative 2 represents the lower bound of the range of annual stringency increases NHTSA believes includes the maximum feasible stringency.
- Alternative 3 (Preferred) – 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 49.6 mpg in MY 2025. For passenger cars, the annual increase in the stringency between model years 2017 and 2021 averages 4.1 percent. In recognition of manufacturers' unique challenges in improving the fuel economy and GHG emissions of full-size pickup trucks while preserving the utility (e.g., towing and payload capabilities) of those vehicles, NHTSA is proposing a slower annual rate of improvement for light trucks in the first phase of the program. For light trucks, the proposed annual increase in stringency in MYs 2017 through 2021 averages 2.9 percent per year. In the second phase of the program (MYs 2022–2025), the annual increase in stringency for passenger cars is expected to average 4.3 percent, and for light trucks, 4.7 percent.
- Alternative 4 – Alternative 4 would require a 7 percent average annual fleetwide increase in mpg for both passenger cars and light trucks for MYs 2017–2025. Alternative 4 represents the upper bound of the range of annual stringency increases NHTSA believes includes the maximum feasible stringency.

The range under consideration in the alternatives encompasses a spectrum of possible standards the agency could select, based on the different ways NHTSA could weigh EPCA's four statutory factors. By providing environmental analyses of these points and the Preferred Alternative, the decisionmaker and the public can determine the environmental effects of points that fall between Alternatives 2 and 4. The action alternatives evaluated in this EIS therefore provide decisionmakers with the ability to select from a wide variety of other potential alternatives with stringencies that increase annually at average percentage rates between 2 and 7 percent. This includes, for example, alternatives with stringencies that increase at different rates for passenger cars and for light trucks and stringencies that increase by different rates in different years.

The agency's Preferred Alternative represents the required fuel economy level NHTSA has tentatively determined to be the maximum feasible level under EPCA, based on balancing the four statutory factors and other relevant considerations. For a detailed explanation of the alternatives, *see* Section 2.2 of this EIS.

These alternatives reflect differences in the degree of technology adoption across the fleet, in costs to manufacturers and consumers, and in conservation of oil and related reductions in GHGs. For example, the most stringent alternative NHTSA is evaluating (Alternative 4) would require greater adoption of technology across the fleet, including more advanced technology, than the least stringent alternative NHTSA is evaluating. As a result, the most stringent alternative would impose greater costs and achieve greater energy conservation and related reductions in GHGs than other action alternatives, compared to the No Action Alternative.

POTENTIAL ENVIRONMENTAL CONSEQUENCES

This section describes how the Proposed Action and alternatives could affect energy use, air quality, and climate. The EIS also qualitatively describes potential additional impacts on water resources, biological resources, safety, hazardous materials and regulated wastes, noise, and environmental justice. Appendix A to the EIS provides the impacts of the proposed standards for passenger cars and light trucks separately.

The impacts on energy use, air quality, and climate described in this Summary include *direct*, *indirect*, and *cumulative impacts*. Direct impacts occur at the same time and place as the action. Indirect impacts occur later in time or are farther removed in distance. Cumulative impacts are the incremental impacts resulting from the action added to those of other past, present, and reasonably foreseeable future actions.

The analysis of the direct and indirect impacts of the proposed standards compares the action alternatives of a particular analysis (A or B) with the No Action Alternative for that analysis, applying their respective assumptions as described above. The cumulative impacts analysis accounts for past, present, and reasonably foreseeable future actions, consistent with NEPA requirements. The cumulative impacts analysis presents the environmental impacts (including impacts to energy, air quality, and climate) due to the fuel economy improvements that result directly or indirectly from the proposed rule in addition to reasonably foreseeable improvements in fuel economy caused by other actions – that is, fuel economy improvements that would result from actions taken by manufacturers without the agency's action and in response to market demands.

Energy

NHTSA's proposed standards would regulate fuel economy and therefore impact U.S. transportation sector fuel consumption. Transportation fuel comprises a large portion of total U.S. energy consumption and energy imports and has a significant impact on the functioning of the energy sector as a whole. Because automotive fuel consumption is expected to account for most U.S. net energy imports through 2035, the United States has the potential to achieve large reductions in imported oil use and, consequently, in the country's net energy imports during this time, by increasing the fuel economy of its fleet of passenger cars and light trucks.

Increasing the fuel economy of the light-duty vehicle fleet is likely to have far-reaching impacts related to reducing U.S. dependence on foreign oil. Reducing dependence on energy imports is a key component of the President's March 30, 2011, *Blueprint for a Secure Energy Future*, which indicates that increasing transportation efficiency is an essential step toward that goal.

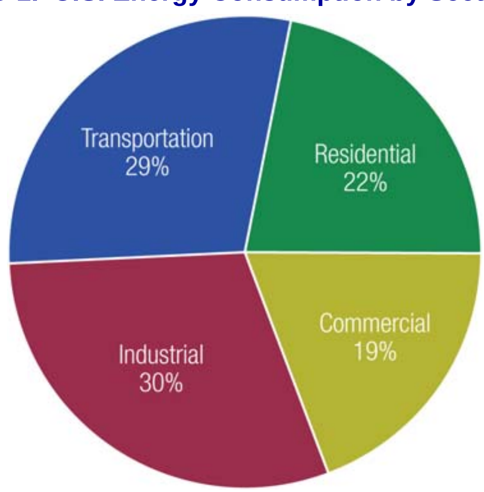
DOE has stated that vehicle efficiency has the greatest short- to mid-term impact on oil consumption.

Energy intensity measures the efficiency at which energy is converted to Gross Domestic Product (GDP), with a high value indicating an inefficient conversion of energy to GDP and a lower value indicating a more efficient conversion. The energy intensity of the U.S. economy was reduced by 54 percent over 4 decades (from 15,890 British thermal units [Btu] per real dollar of GDP in 1970 to 7,330 Btu per real dollar of GDP in 2009), indicating an overall increase in the efficiency with which the U.S. uses energy. Although U.S. energy efficiency has been increasing and the U.S. share of global energy consumption has been declining in recent decades, total U.S. energy consumption has been increasing over that same period.

Most of the increase in U.S. energy consumption over the past decades has not come from increased domestic energy production, but instead from the increase in imports largely for use in the transportation sector. Transportation fuel consumption has grown steadily on an annual basis. Transportation is now the largest consumer of petroleum in the U.S. economy and a major contributor to U.S. net imports. The United States is poised to reverse the trend of the last 4 decades and achieve large reductions in net energy imports through 2035 due to continuing increases in U.S. energy efficiency and recent developments in U.S. energy production. Stronger fuel economy standards for light-duty vehicles have the potential to further increase U.S. energy efficiency in the transportation sector and reduce U.S. dependence on petroleum.

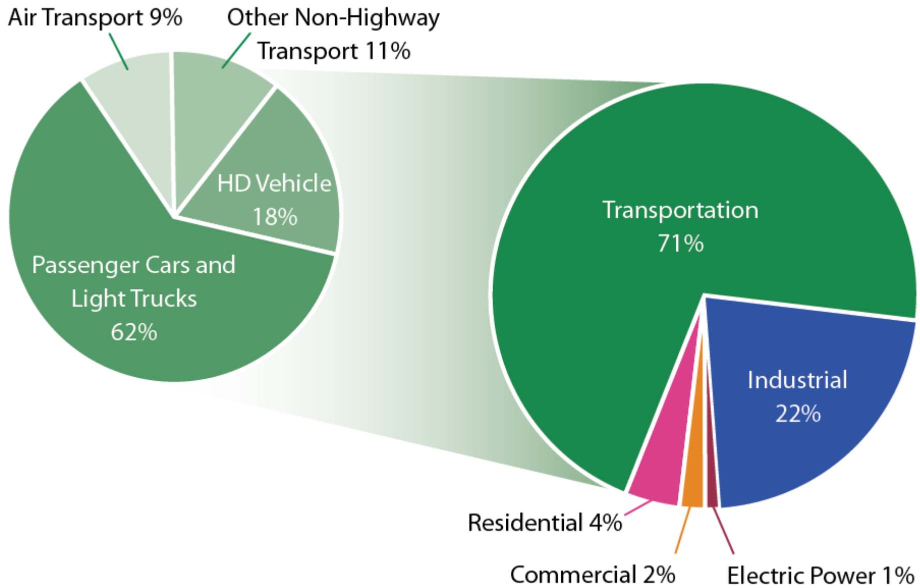
The transportation sector is the second-largest consumer of energy in the United States (after the industrial sector), representing 29 percent of total U.S. energy use, as shown in Figure S-1. Petroleum is by far the largest source of energy used in the transportation sector, accounting for almost 95 percent of this sector's energy consumption. Consequently, transportation accounts for the largest share of total U.S. petroleum consumption. As shown in Figure S-2, 71 percent of the petroleum used in the United States is consumed by the transportation sector.

Figure S-1. U.S. Energy Consumption by Sector, 2009



Source: EIA (Energy Information Administration). 2011. Annual Energy Review 2010. Table 2.1a—Energy Consumption by Sector, Selected Years, 1949–2010. DOE/EIA-0384(2010). U.S. Department of Energy: Washington, D.C. Available at: <http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf>. (Accessed: November 2, 2011).

Figure S-2. U.S. Petroleum Consumption by Sector, 2009



HD = heavy-duty

Left Pie Chart Data Source: EIA. 2011. Annual Energy Outlook 2011. Table 7—Transportation Sector key Indicators and delivered energy Consumption, reference Case, 2008-2035. DOE/EIA-0383 (2011), April. U.S. Department of Energy: Washington, D.C. Available at: <http://www.eia.gov/oiaf/aeo/tablebrowser/>. (Accessed: October 18, 2011).

Right Pie Chart Data Source: EIA. 2011. Annual Energy Review 2010. Table 5.13a-d—Petroleum Consumption Estimates, 1949–2010. DOE/EIA-0384 (2010). U.S. Department of Energy: Washington, D.C. Available at: <http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf>. (Accessed: October 27, 2011).

More than half of transportation sector energy use can be attributed to petroleum (gasoline and diesel fuel) consumption from passenger cars and light trucks. In the future, the transportation sector will continue to be the largest petroleum consumer and the second-largest component of total U.S. energy consumption after the industrial sector. NHTSA's analysis of fuel consumption in this EIS assumes that fuel consumed by passenger cars and light trucks will consist predominantly of gasoline and diesel fuel derived from petroleum for the foreseeable future.

Key Findings for Energy Use

To calculate fuel savings for each proposed alternative, NHTSA subtracted projected fuel consumption under each action alternative from the level under the No Action Alternative. The fuel consumption and savings figures presented below are for 2017 through 2060 (the year by which nearly the entire U.S. light-duty vehicle fleet will likely be composed of MY 2017–2025 and later vehicles).

Direct and Indirect Impacts

As the alternatives increase in stringency, total fuel consumption decreases under both Analysis A and Analysis B. Total combined gas and diesel fuel consumption by all U.S. passenger cars and light trucks during the period 2017–2060 would decrease from approximately 7,000 billion gallons under the No Action Alternative (7,092 in Analysis A; 6,421 in Analysis B) to approximately 5,000 billion gallons under Alternative 4 (5,216 in Analysis A; 4,964 in Analysis B). Total fuel consumption under the Preferred Alternative falls between these two levels, amounting to 5,860 billion gallons in Analysis A and 5,583 billion gallons in Analysis B during the period 2017–2060.

Fuel savings is the reduction in fuel consumption over a specific period. In contrast to fuel consumption, fuel savings under each action alternative compared to the No Action Alternative increases with stringency. Figures S-3-A and S-3-B demonstrate fuel savings for Analysis A and Analysis B, respectively, from 2017–2060 under each alternative compared to the No Action Alternative. Total fuel savings from 2017–2060 compared to the No Action Alternative ranges from a low of approximately 731 billion gallons in Analysis A (446 billion gallons in Analysis B) under Alternative 2 to a high of approximately 1,877 billion gallons in Analysis A (1,457 billion gallons in Analysis B) under Alternative 4. Total fuel savings under the Preferred Alternative falls between these two levels, amounting to 1,232 billion gallons in Analysis A and 838 billion gallons in Analysis B during the period 2017–2060.

Figure S-3-A. U.S. Passenger Car and Light Truck Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Direct and Indirect Impacts (Analysis A)

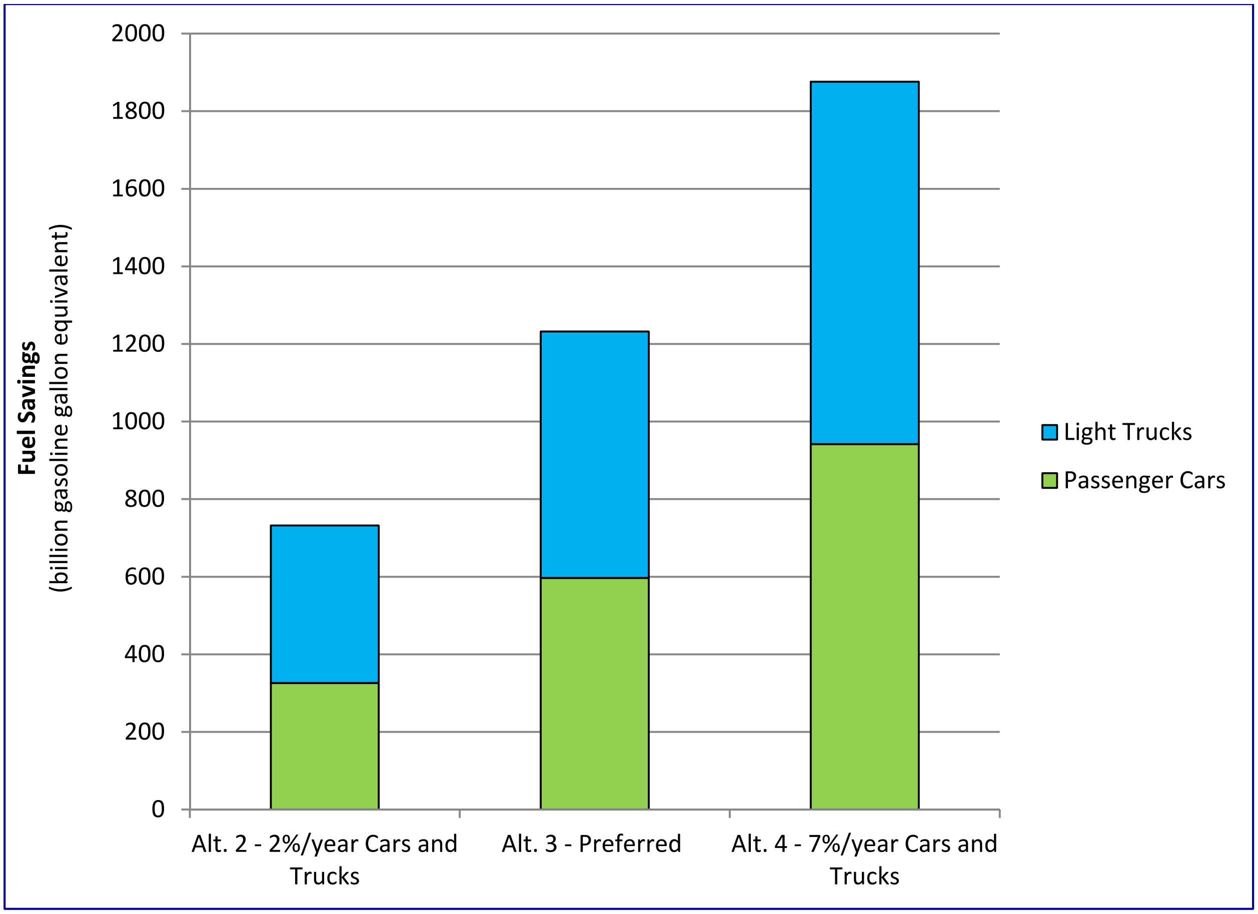
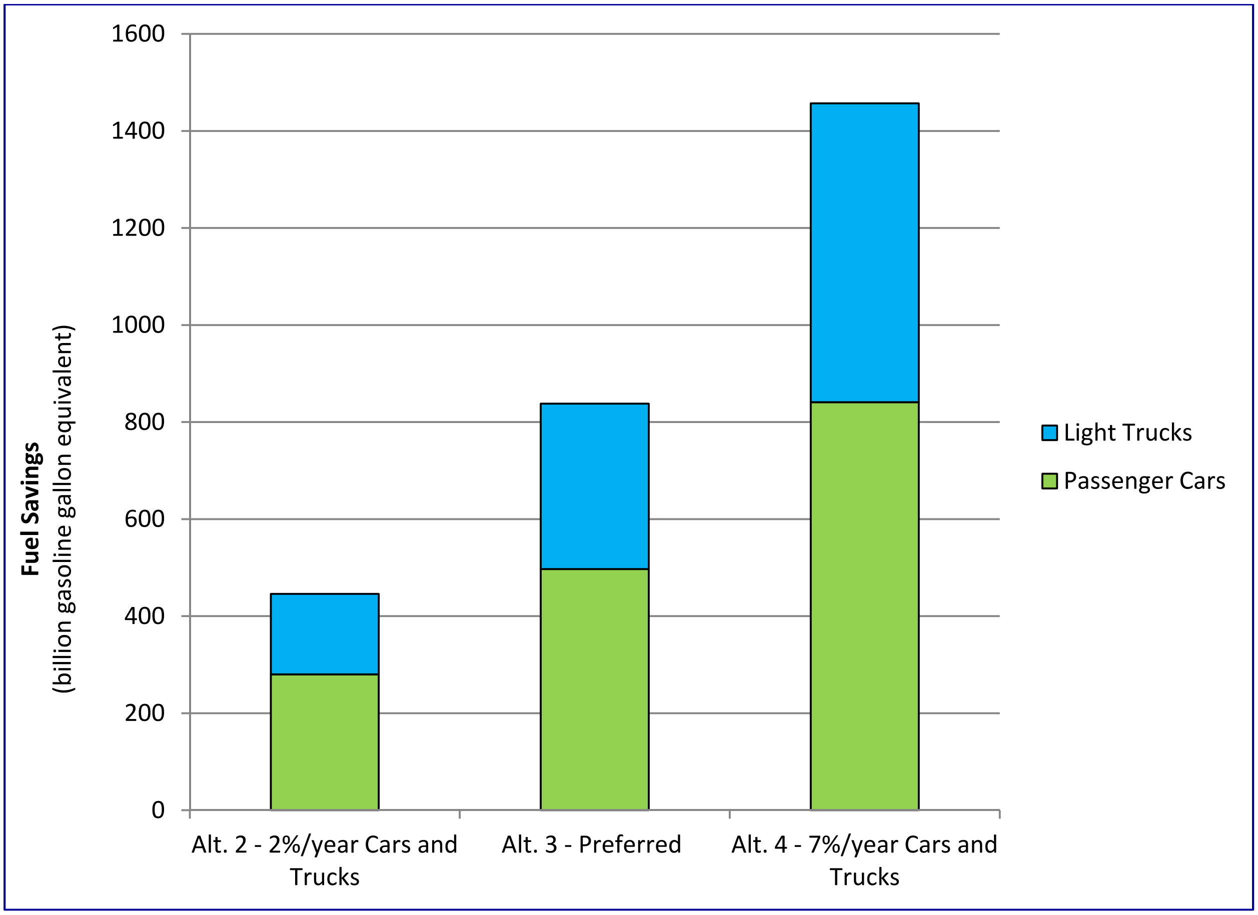


Figure S-3-B. U.S. Passenger Car and Light Truck Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Direct and Indirect Impacts (Analysis B)

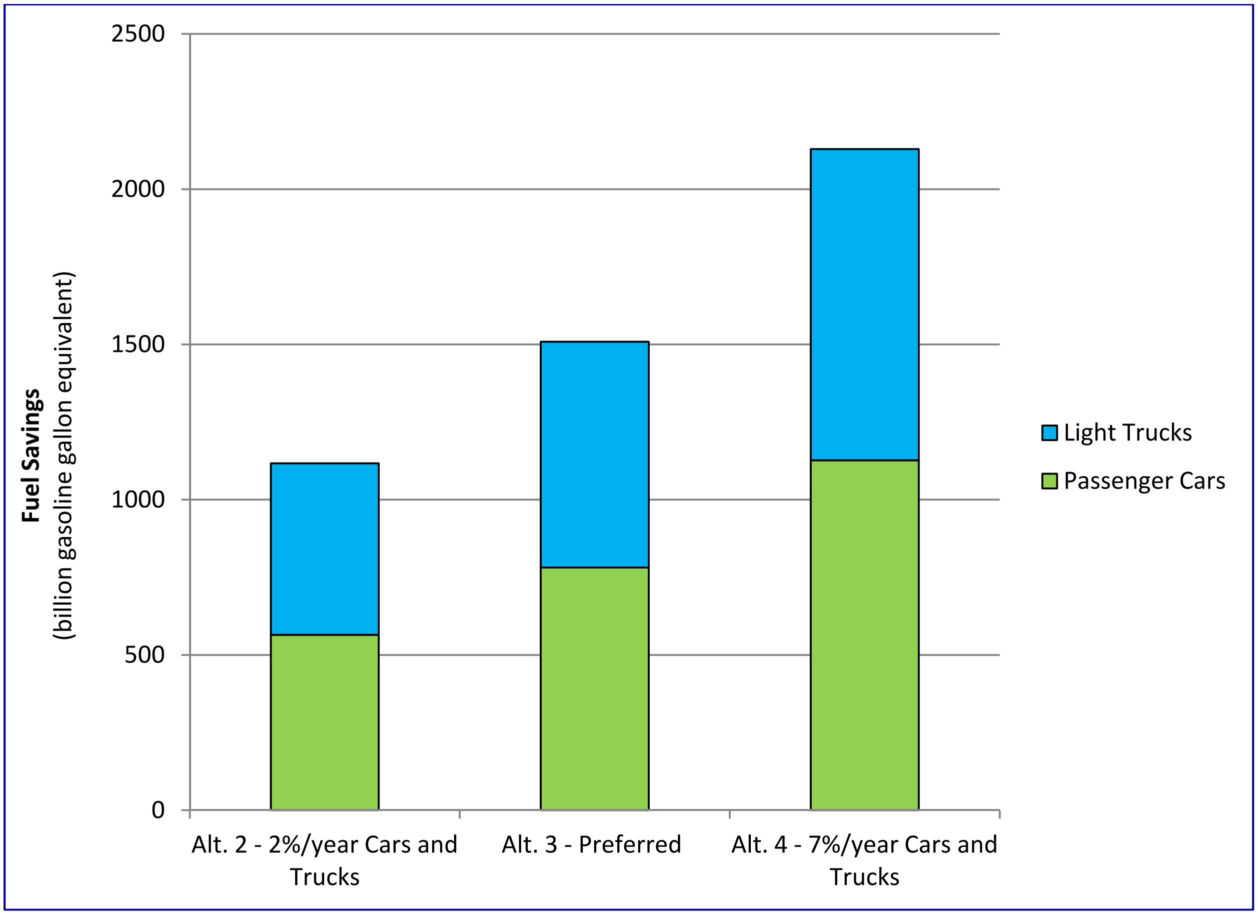


Cumulative Impacts

As with direct and indirect impacts, fuel consumption under each alternative will decrease with increasing stringency under the cumulative impacts analysis, which incorporates other past, present, and reasonably foreseeable future actions. Under the No Action Alternative, total combined gas and diesel fuel consumption during the period 2017–2060 would be 7,092 billion gallons. Total fuel consumption under the action alternatives ranges from a low of 4,964 billion gallons under Alternative 4 to a high of 5,975 billion gallons under Alternative 2. Total fuel consumption under the Preferred Alternative falls between these levels, amounting to 5,583 billion gallons.

Similarly, under the cumulative impacts analysis, fuel savings from passenger cars and light trucks increase with increased fuel economy stringency. Figure S-4 demonstrates fuel savings for the period 2017–2060 under each alternative compared to the No Action Alternative. Fuel savings during this period range from a low of 1,117 billion gallons under Alternative 2 to a high of 2,128 billion gallons under Alternative 4. Under the cumulative impacts analysis, fuel savings under the Preferred Alternative falls between these levels, amounting to 1,509 billion gallons.

Figure S-4. U.S. Passenger Car and Light Truck Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Cumulative Impacts



Air Quality

Air pollution and air quality can affect public health, public welfare, and the environment. The alternative MY 2017–2025 CAFE standards under consideration would affect air pollutant emissions and air quality. The EIS air quality analysis assesses the impacts of the alternatives in relation to emissions of pollutants of concern from mobile sources, the resulting impacts to human health, and the monetized health benefits of emissions reductions. Although air pollutant emissions generally decline under the action alternatives compared to the No Action Alternative, the magnitudes of the declines are not consistent across all pollutants (and some air pollutant emissions might increase), reflecting the complex interactions between tailpipe emission rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers to comply with the standards, upstream emission rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and increases in vehicle miles traveled (VMT).

Under the authority of the Clean Air Act (CAA) and its amendments, EPA has established National Ambient Air Quality Standards (NAAQS) for six relatively common air pollutants – known as “criteria” pollutants because EPA regulates them by developing human-health-based or environmentally-based criteria for setting permissible levels. The criteria pollutants are carbon monoxide (CO), nitrogen dioxide (NO_2), ozone, sulfur dioxide (SO_2), lead, and particulate matter (PM) with an aerodynamic diameter equal to or less than 10 microns (PM_{10})

and 2.5 microns ($PM_{2.5}$, or fine particles). Ozone is not emitted directly from vehicles, but is formed from emissions of the ozone precursor pollutants nitrogen oxides (NO_x) and volatile organic compounds (VOCs).

In addition to criteria pollutants, motor vehicles emit some substances defined by the 1990 CAA Amendments as hazardous air pollutants. Hazardous air pollutants include certain VOCs, compounds in PM, pesticides, herbicides, and radionuclides that present tangible hazards based on scientific studies of human (and other mammal) exposure.

Hazardous air pollutants from vehicles are known as mobile source air toxics (MSATs). The MSATs included in this analysis are acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter (DPM), and formaldehyde. EPA and the Federal Highway Administration have identified these air toxics as the MSATs that typically are of greatest concern when analyzing impacts of highway vehicles. DPM is a component of exhaust from diesel-fueled vehicles and falls almost entirely within the $PM_{2.5}$ particle-size class.

Health Effects of the Pollutants

The criteria pollutants assessed in the EIS have been shown to cause a range of adverse health effects at various concentrations and exposures, including:

- Damage to lung tissue
- Reduced lung function
- Exacerbation of existing respiratory and cardiovascular diseases
- Difficulty breathing
- Irritation of the upper respiratory tract
- Bronchitis and pneumonia
- Reduced resistance to respiratory infections
- Alterations to the body's defense systems against foreign materials
- Reduced delivery of oxygen to the body's organs and tissues
- Impairment of the brain's ability to function properly
- Cancer and premature death.

MSATs are also associated with adverse health effects. For example, EPA classifies acetaldehyde, benzene, 1,3-butadiene, formaldehyde, and certain components of DPM as either known or probable human carcinogens. Many MSATs are also associated with non-cancer health effects, such as respiratory irritation.

Contribution of U.S. Transportation Sector to Air Pollutant Emissions

The U.S. transportation sector is a major source of emissions of certain criteria pollutants or their chemical precursors. Emissions of these pollutants from on-road mobile sources have declined dramatically since 1970 as a result of pollution controls on vehicles and regulation of the chemical content of fuels.

Highway vehicles (including vehicles covered by the proposed rule) are responsible for approximately 53 percent of total U.S. emissions of CO, 1.7 percent of $PM_{2.5}$ emissions, and 1.2 percent of PM_{10} emissions. Highway vehicles also contribute approximately 24 percent of total nationwide emissions of VOCs and 31 percent of NO_x, both of which are chemical precursors of ozone. In addition, NO_x is a $PM_{2.5}$ precursor and VOCs can be $PM_{2.5}$ precursors. Highway vehicles contribute less than 0.4 percent of SO_2, but SO_2 and other oxides of sulfur (SO_x) are important because they contribute to the formation of $PM_{2.5}$ in the atmosphere. With the elimination of lead in automotive gasoline, it is no longer emitted from motor vehicles in more than negligible quantities and therefore is not assessed in this analysis.

Key Findings for Air Quality

The findings for air quality effects are shown for 2040 in this Summary, a mid-term forecast year by which time a large proportion of passenger car and light truck VMT would be accounted for by vehicles that meet the MY 2017–2025 standards. The results reported in this section apply to both Analysis A and Analysis B for 2040, unless otherwise noted. The EIS provides findings for air quality effects for 2021, 2025, 2040, and 2060.

In general, emissions of criteria and toxic air pollutants decrease with increased stringency across alternatives. This trend is true for all criteria pollutants except CO and SO_2, which would have higher emissions under some of the action alternatives than under the No Action Alternative. Under the Preferred Alternative, emissions of all criteria air pollutants would be lower than under the No Action Alternative, except for CO and NO_x which in some years would be slightly higher.

Toxic air pollutants are more variable in their response to increasing fuel economy. Compared to the No Action Alternative, the action alternatives result in reduced emissions of benzene and DPM, but slightly higher emissions of formaldehyde and acrolein. Acetaldehyde and 1,3-butadiene emissions would be higher or lower than the No Action Alternative depending on the action alternative. Emissions of all toxic air pollutants would be higher under the Preferred Alternative than under the No Action Alternative for acetaldehyde, formaldehyde, and acrolein; lower for benzene and DPM; and higher or lower for 1,3-butadiene, depending on the year.

The increases and decreases in emissions reflect the complex interactions among tailpipe emission rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the proposed standards, upstream emission rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, the proportion of electric vehicles in the passenger car and light truck population, and increases in VMT.

Monetized $PM_{2.5}$-related health benefits and the associated reduced incidence of adverse health effects from the emission reductions were estimated by multiplying direct $PM_{2.5}$ and $PM_{2.5}$ precursor emission reductions (NO_x, SO_2, and VOCs) by pollutant-specific benefit-per-ton estimates provided by EPA. Reductions in adverse health outcomes include reduced incidences of premature mortality, chronic bronchitis, respiratory emergency room visits, and work-loss days.

Direct and Indirect Impacts

Criteria Pollutants

- Emissions of criteria pollutants are highest under the No Action Alternative and generally decline as fuel consumption decreases from the least stringent alternative (No Action) to the most stringent (Alternative 4), as shown in Figures S-5-A and S-5-B. CO and SO_2 are exceptions to this general trend, with CO emissions increasing under Alternative 2, decreasing under the Preferred Alternative and then decreasing further under Alternative 4, and SO_2 emissions decreasing under Alternative 2 and the Preferred Alternative and then increasing under Alternative 4.

- Emissions of CO, NO_x, $PM_{2.5}$, and VOCs generally are lowest under Alternative 4, while emissions of SO_2 are lowest under the Preferred Alternative.
- Under the Preferred Alternative, emissions of all criteria pollutants would be reduced compared to the No Action Alternative, except CO emissions, which would increase slightly from the No Action Alternative. Excluding CO, emissions under the Preferred Alternative generally would be lower than emissions under Alternative 2, but higher than emissions under Alternative 4. Emissions of CO and SO_2 vary inconsistently by alternative and year.

Figure S-5-A. Nationwide Criteria Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2040 by Alternative, Direct and Indirect Impacts (Analysis A)

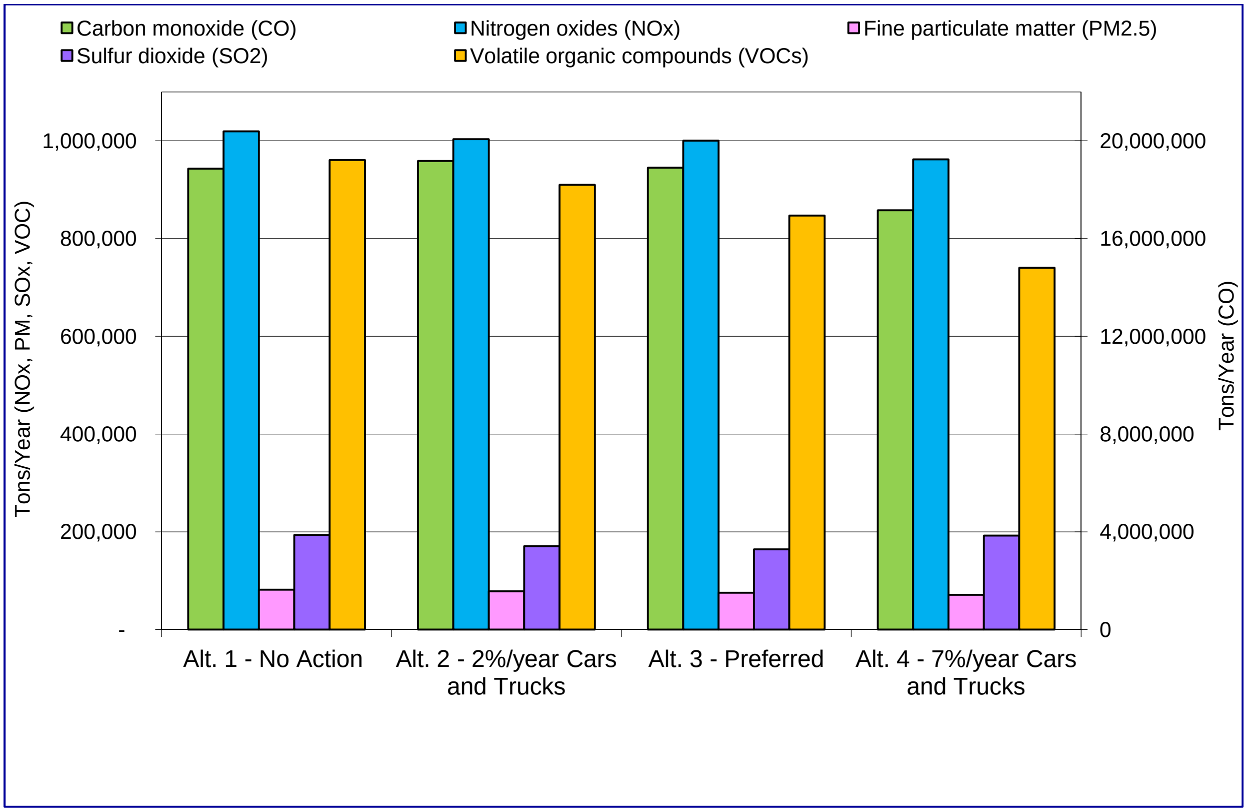
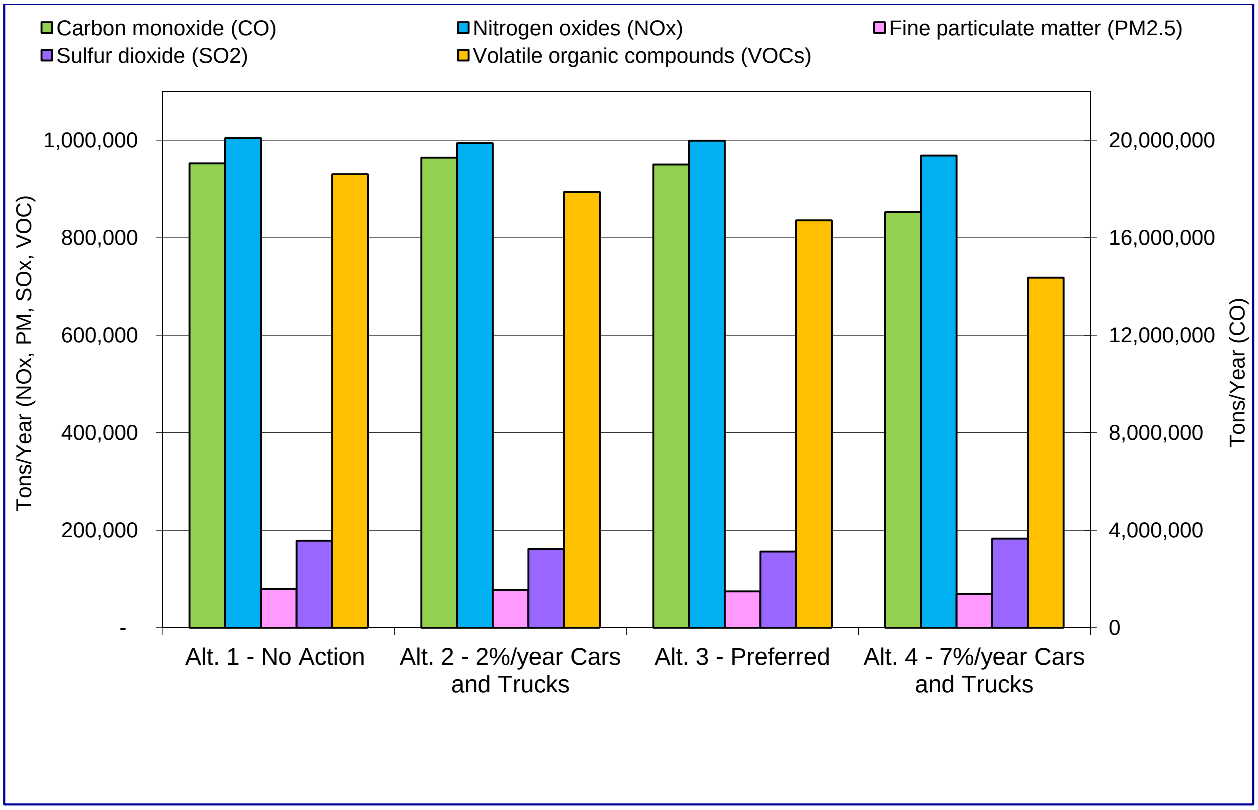


Figure S-5-B. Nationwide Criteria Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2040 by Alternative, Direct and Indirect Impacts (Analysis B)



Hazardous Air Pollutants

- Emissions of benzene are highest under the No Action Alternative and decline as fuel consumption decreases across the alternatives, as shown in Figures S-6-A and S-6-B. Emissions of acetaldehyde and 1,3-butadiene generally increase under Alternative 2 and the Preferred Alternative and decrease under Alternative 4. Emissions of DPM generally decrease under Alternatives 2 and 3, but increase under Alternative 4. Emissions of acrolein and formaldehyde increase for all action alternatives compared to the No Action Alternative.
- Emissions of acetaldehyde, benzene, and 1,3-butadiene are lowest under Alternative 4 in most years, while emissions of acrolein and formaldehyde are lowest under the No Action Alternative. Emissions of DPM are lowest under Alternative 2, the Preferred Alternative, or Alternative 4, depending on the year.
- Under the Preferred Alternative, emissions of benzene, 1,3-butadiene (in some years), and DPM (in some years) would be reduced compared to the No Action Alternative. In contrast, emissions of acetaldehyde, acrolein, and formaldehyde would increase under the Preferred Alternative compared to the No Action Alternative. Emissions of benzene, 1,3-butadiene, and DPM under the Preferred Alternative would be lower than under Alternative 2 in most years, and either higher or lower than under Alternative 4, depending on the pollutant, year, and analysis. Emissions of acetaldehyde, acrolein, and formaldehyde under the Preferred Alternative would be higher than under Alternative 2 and either higher or lower than under Alternative 4, depending on the pollutant, year, and analysis.

Figure S-6-A. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2040 by Alternative, Direct and Indirect Impacts (Analysis A)

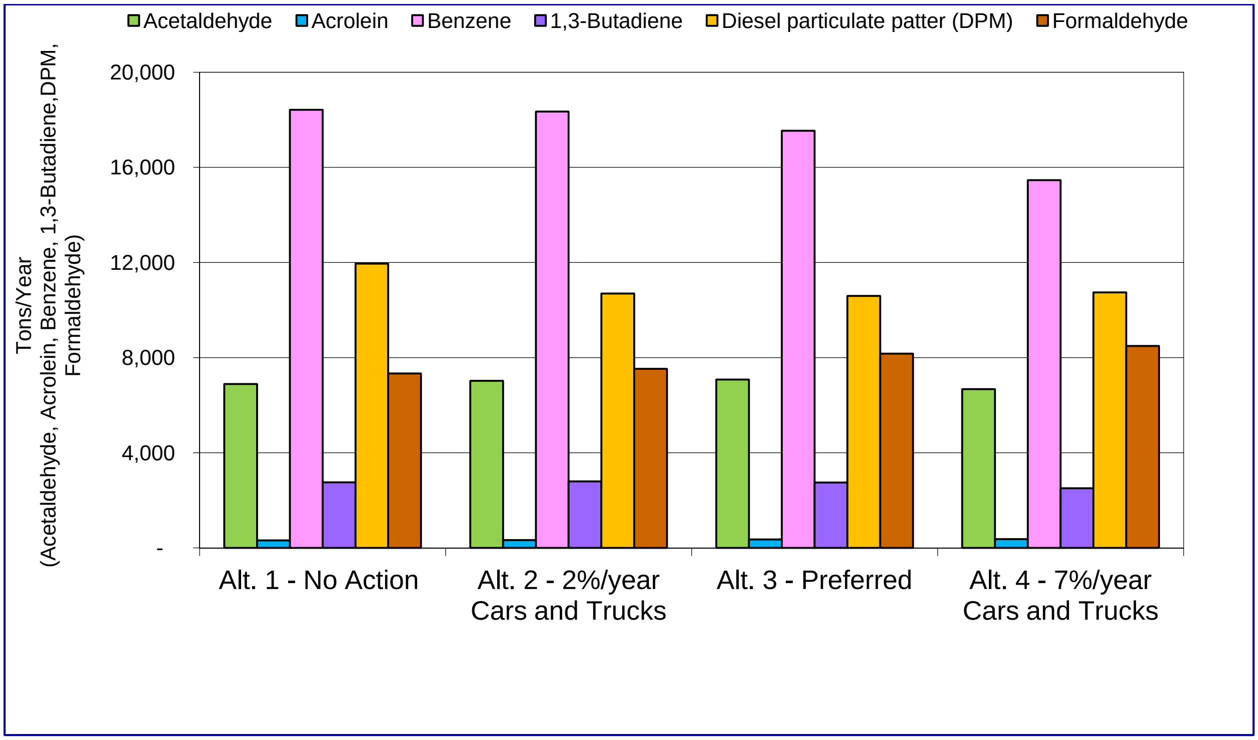
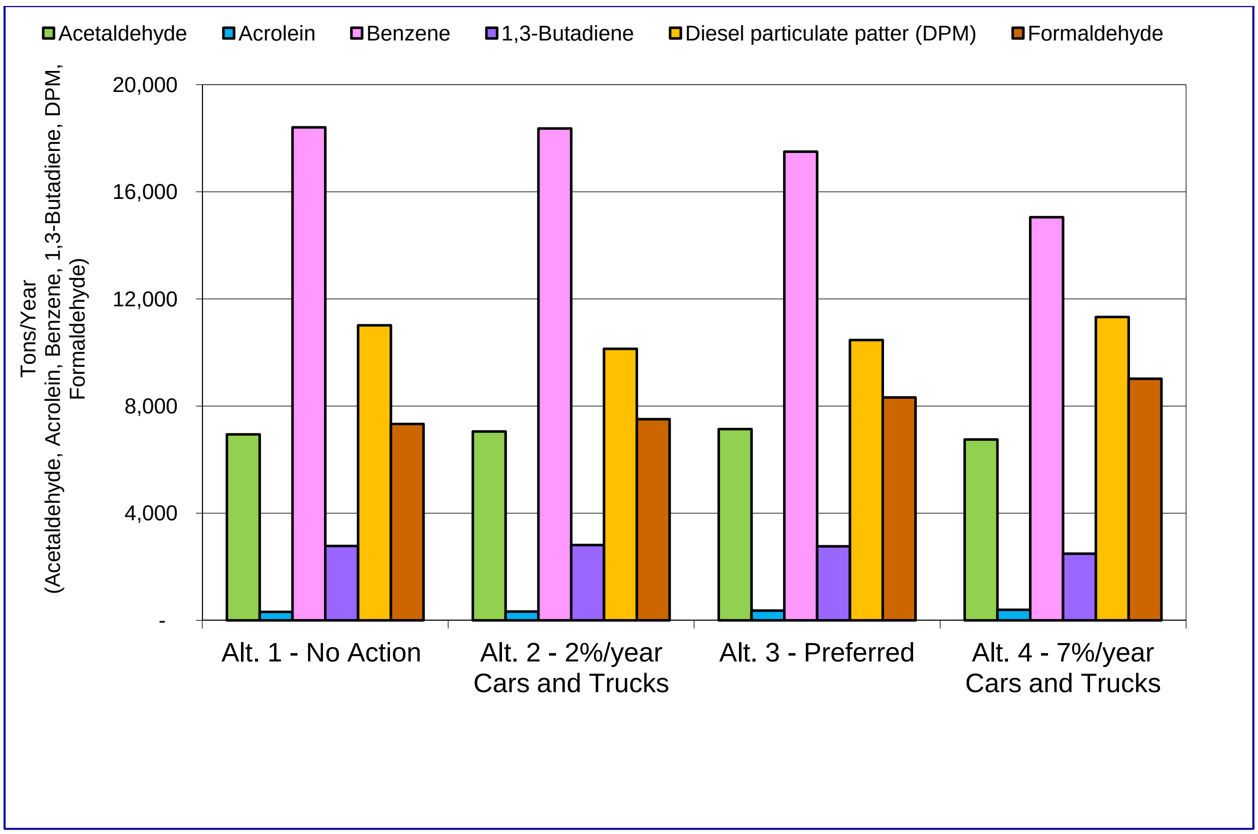


Figure S-6-B. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2040 by Alternative, Direct and Indirect Impacts (Analysis B)



Health and Monetized Health Benefits

- All action alternatives would result in reduced adverse health effects (mortality, chronic bronchitis, emergency room visits for asthma, and work-loss days) nationwide compared to the No Action Alternative. Reductions increase as fuel consumption decreases across alternatives.
- Because monetized health benefits increase with reductions in adverse health effects, monetized benefits would increase across alternatives along with increasing fuel economy standards. When estimating quantified and monetized health impacts, EPA relies on results from two $PM_{2.5}$-related premature mortality studies it considers equivalent: Pope et al. (2002) and Laden et al. (2006). EPA recommends that monetized benefits be shown using incidence estimates derived from each of these studies and valued using both a 3 percent and a 7 percent discount rate to account for an assumed lag in the occurrence of mortality after exposure, for a total of four separate calculations of monetized health benefits. Estimated monetized health benefits in 2040 range from a low of $1.6 billion in Analysis A ($1.1 billion in Analysis B) for Alternative 2 (using the lowest of the four calculations) to a high of $9.6 billion in Analysis A ($8.8 billion in Analysis B) for Alternative 4 (using the highest of the four calculations).
- Under the Preferred Alternative, adverse health outcomes would be fewer and monetized health benefits would be greater than under the No Action Alternative and Alternative 2; however, adverse health outcomes would be greater and monetized health benefits would be less than under Alternative 4.

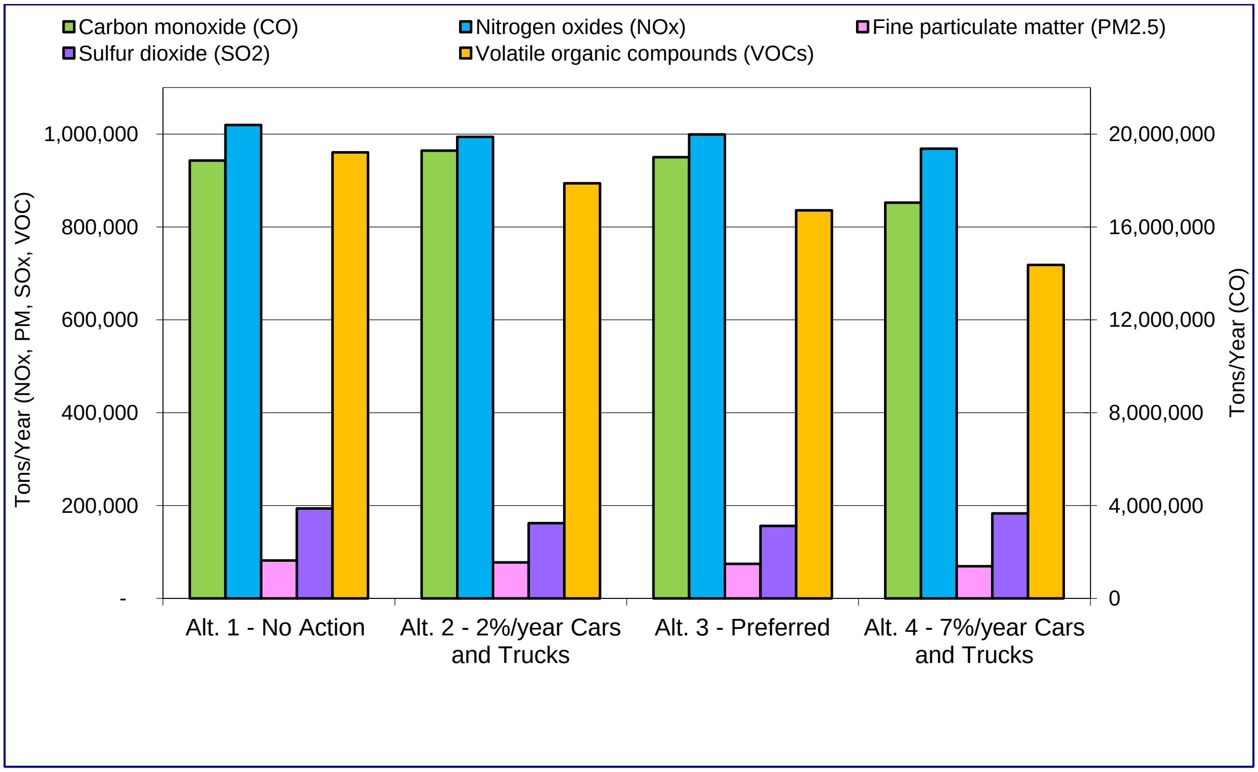
See Section 4.2 of this EIS for data on the direct effects of criteria and hazardous air pollutant emissions, as well as monetized health benefits for the alternatives.

Cumulative Impacts

Criteria Pollutants

- Cumulative emissions of criteria pollutants are highest under the No Action Alternative and generally decline as fuel consumption decreases across the action alternatives, as shown in Figure S-7. CO and SO_2 are exceptions to this general trend, with CO emissions increasing under Alternative 2, decreasing under the Preferred Alternative and then decreasing further under Alternative 4, and SO_2 emissions decreasing through the Preferred Alternative and then increasing under Alternative 4 but remaining less than emissions under the No Action Alternative.
- Emissions of CO, $PM_{2.5}$, and VOCs are lowest under Alternative 4, while emissions of NO_x and SO_2 are lowest under the Preferred Alternative or Alternative 4, depending on the year.
- Under the Preferred Alternative, emissions of all criteria pollutants would be reduced compared to the No Action Alternative, except for CO emissions, which would be slightly higher under the Preferred Alternative than under the No Action Alternative. Emissions of all criteria pollutants under the Preferred Alternative would be lower than emissions under Alternative 2, but higher than emissions under Alternative 4, with the exception of NO_x and SO_2 emissions, which are higher under the Preferred Alternative or Alternative 4 depending on the year.

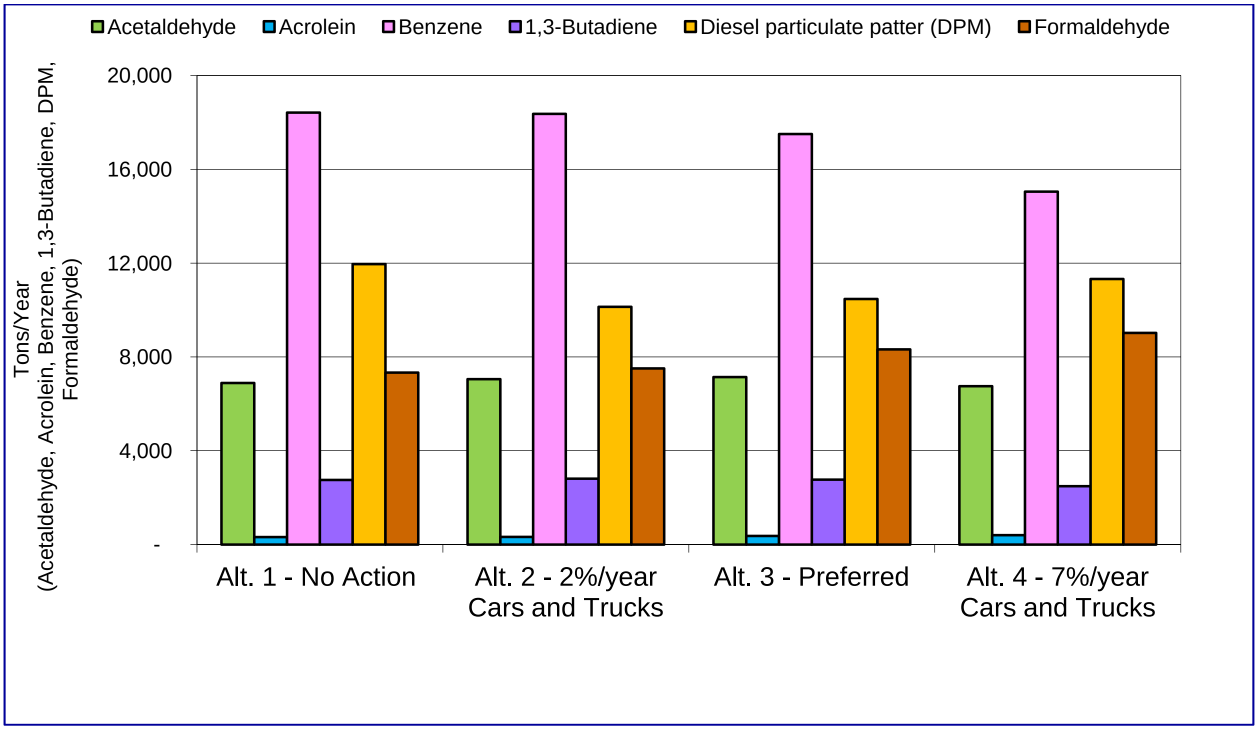
Figure S-7. Nationwide Criteria Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2040 by Alternative, Cumulative Impacts



Hazardous Air Pollutants

- Emissions of benzene generally are highest under the No Action Alternative and decline as fuel consumption decreases across the action alternatives, as shown in Figure S-8. Emissions of acetaldehyde increase under Alternative 2 and the Preferred Alternative and generally decrease under Alternative 4, and emissions of 1,3-butadiene increase under Alternative 2 and generally decrease under the Preferred Alternative and Alternative 4. Emissions of DPM are highest under the No Action Alternative and decrease, although not consistently, across the action alternatives. Emissions of acrolein and formaldehyde increase with decreasing fuel consumption across all the action alternatives.
- Emissions of acetaldehyde, benzene, and 1,3-butadiene generally are lowest under Alternative 4, while emissions of acrolein and formaldehyde are lowest under the No Action Alternative. Emissions of DPM are the lowest under Alternative 2, the Preferred Alternative, or Alternative 4, depending on the year.
- Under the Preferred Alternative, emissions of benzene, 1,3-butadiene (in some years), and DPM (in some years) would be reduced compared to the No Action Alternative. In contrast, emissions of acetaldehyde (in some years), acrolein, and formaldehyde would increase under the Preferred Alternative compared to the No Action Alternative. Emissions of benzene and 1,3-butadiene under the Preferred Alternative generally would be lower than under Alternative 2 and higher than under Alternative 4. Emissions of acetaldehyde, acrolein, 1,3-butadiene (in some years), DPM (in some years), and formaldehyde under the Preferred Alternative would be higher than under Alternative 2. Emissions of acetaldehyde under the Preferred Alternative would be higher (in some years) than under Alternative 4, while emissions of acrolein, DPM, and formaldehyde under the Preferred Alternative generally would be lower than under Alternative 4.

Figure S-8. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2040 by Alternative, Cumulative Impacts



Health and Monetized Health Benefits

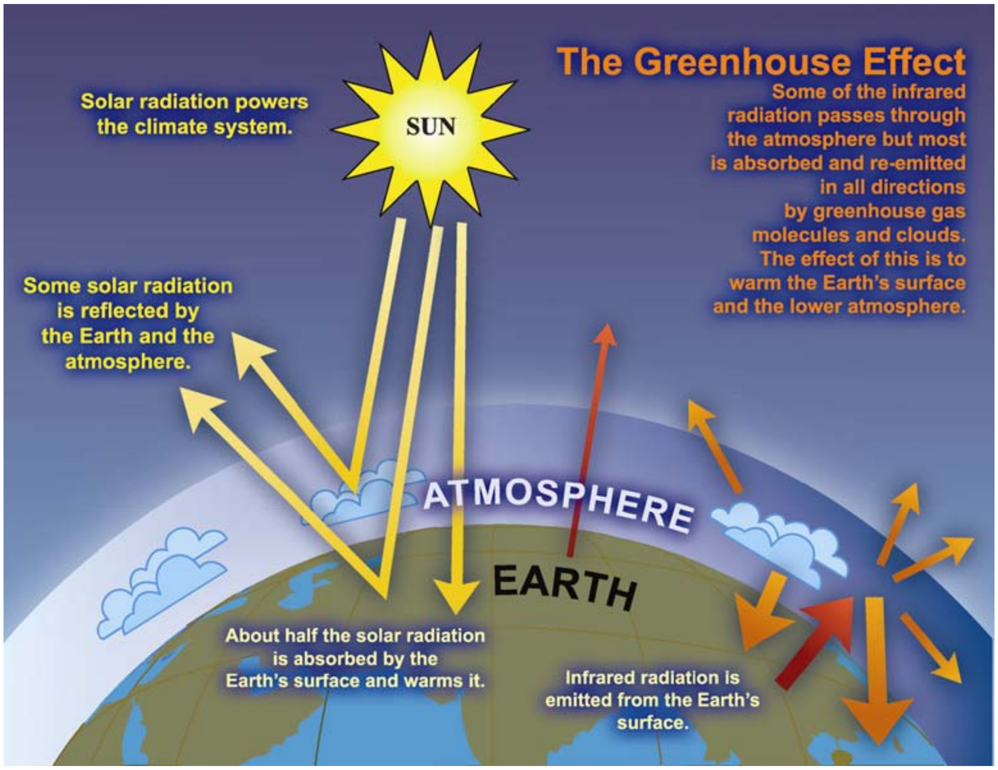
- Alternatives 2 through 4 would result in reduced adverse health effects nationwide compared to the No Action Alternative. Reductions generally increase as fuel consumption decreases across alternatives.
- The monetized health benefits follow the same patterns as the reductions in adverse health effects. Estimated annual monetized health benefits in 2040 range from a low of $2.2 billion under Alternative 2 (lowest of the four calculations) to a high of $11.7 billion under Alternative 4 (highest of the four calculations).
- Under the Preferred Alternative, cumulative adverse health outcomes would be fewer and monetized health benefits would be greater than under the No Action Alternative and Alternative 2. Cumulative adverse health outcomes would be greater and monetized health benefits would be less under the Preferred Alternative than under Alternative 4.

See Section 4.2 of this EIS for cumulative effects data on criteria and hazardous air pollutant emissions, as well as monetized health benefits for the alternatives.

Climate

Earth's natural greenhouse effect is responsible for maintaining surface temperatures warm enough to sustain life (*see* Figure S-9). CO_2 and other GHGs trap heat in the troposphere (the layer of the atmosphere that extends from Earth's surface up to approximately 8 miles), absorb heat energy emitted by Earth's surface and its lower atmosphere, and radiate much of it back to the surface. Without GHGs in the atmosphere, most of this heat energy would escape back to space.

Figure S-9. The Greenhouse Effect



Source: IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: The Physical Science Basis. Contribution of working group I to the Fourth Assessment report of the Intergovernmental Panel on Climate Change. [Solomon, S., d. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.l. Miller (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 996 pgs.

The amount of CO_2 and other natural GHGs in the atmosphere – such as methane (CH_4), nitrous oxide (N_2O), water vapor, and ozone – has fluctuated over time, but natural emissions of GHGs are largely balanced by natural sinks, such as vegetation (which, when buried and compressed over long periods, becomes fossil fuel) and the oceans, which remove the gases from the atmosphere.

Since the industrial revolution, when fossil fuels began to be burned in increasing quantities, concentrations of GHGs in the atmosphere have increased. CO_2 has increased by more than 38 percent since pre-industrial times, while the concentration of CH_4 is now 149 percent above pre-industrial levels.

This buildup of GHGs in the atmosphere is upsetting Earth's energy balance and causing the planet to warm, which in turn affects sea levels, precipitation patterns, cloud cover, ocean temperatures and currents, and other climatic conditions. Scientists refer to this phenomenon as "global climate change."

During the past century, Earth's surface temperature has risen by an average of approximately 0.74 degrees Celsius (°C) (1.3 degrees Fahrenheit [°F] and sea levels have risen 0.17 meter (6.7 inches), with a maximum rate of about 2 millimeters (0.08 inch) per year over the past 50 years on the northeastern coast of the United States.

A recent National Research Council (NRC) report stated that there is a strong, credible body of evidence, based on multiple lines of research, documenting that climate is changing and that the changes are largely caused by human activities. These activities – such as the combustion of fossil fuel, the production of agricultural commodities, and the harvesting of trees – contribute to increased concentrations of GHGs in the atmosphere, which in turn trap increasing amounts of heat, altering Earth's energy balance.

Throughout this EIS, NHTSA has relied extensively on findings of the United Nations Intergovernmental Panel on Climate Change (IPCC), the U.S. Climate Change Science Program (CCSP), the NRC, the Arctic Council, the U.S. Global Change Research Program (GCRP), and EPA. Our discussion focuses heavily on the most recent, thoroughly peer-reviewed, and credible assessments of global and U.S. climate change. *See* Section 5.1 of this EIS for more detail.

Impacts of Climate Change

Climate change is expected to have a wide range of effects on temperature, sea level, precipitation patterns, severe weather events, and water resources, which in turn could affect human health and safety, infrastructure, food and water supplies, and natural ecosystems.

- Impacts on freshwater resources could include changes in precipitation patterns; decreasing aquifer recharge in some locations; changes in snowpack and timing of snowmelt; saltwater intrusion from sea-level changes; changes in weather patterns resulting in flooding or drought in certain regions; increased water temperature; and numerous other changes to freshwater systems that disrupt human use and natural aquatic habitats.
- Impacts on terrestrial ecosystems could include shifts in species range and migration patterns, potential extinctions of sensitive species unable to adapt to changing conditions, increases in the occurrence of forest fires and pest infestation, and changes in habitat productivity due to increased atmospheric concentrations of CO_2.
- Impacts on coastal ecosystems could include the loss of coastal areas due to submersion and erosion, additional impacts from severe weather and storm surges, and increased salinization of estuaries and freshwater aquifers.
- Impacts on land use could include flooding and severe-weather impacts on coastal, floodplain and island settlements; extreme heat and cold waves; increases in drought in some locations; and weather- or sea-level-related disruptions of the service, agricultural, and transportation sectors.
- Impacts on human health could include increased mortality and morbidity due to excessive heat, increases in respiratory conditions due to poor air quality, increases in water and food-borne diseases, changes in the seasonal patterns of vector-borne diseases, and increases in malnutrition.

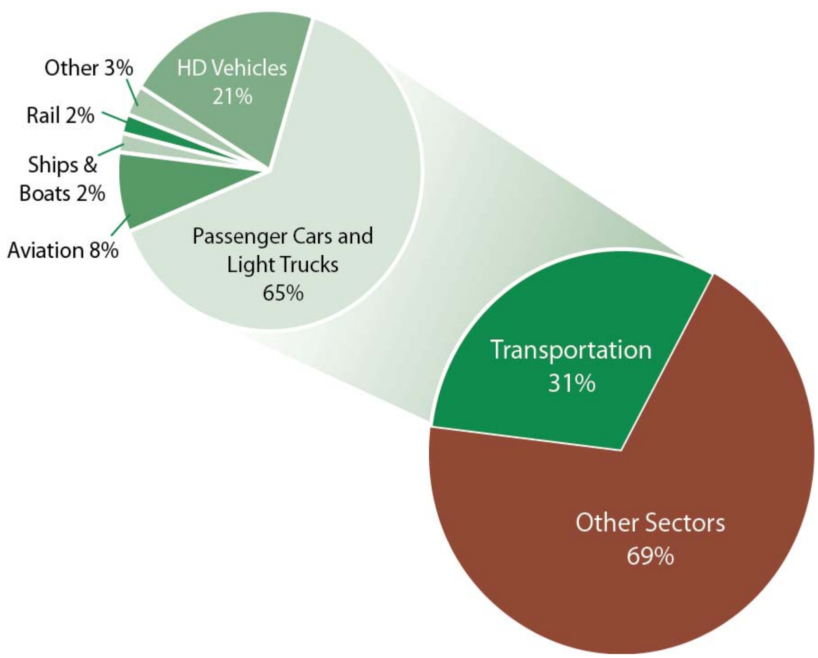
In addition to its role as a GHG in the atmosphere, CO_2 is transferred from the atmosphere to water, plants, and soil. In water, CO_2 combines with water molecules to form carbonic acid. When CO_2 dissolves in seawater, a series of well-known chemical reactions begins that increases the concentration of hydrogen ions and makes seawater more acidic, which has adverse effects on corals and other marine life.

Increased concentrations of CO_2 in the atmosphere can also stimulate plant growth to some degree, a phenomenon known as the CO_2 fertilization effect. The available evidence indicates that different plants respond in different ways to enhanced CO_2 concentrations.

Contribution of the U.S. Transportation Sector to Climate Change

Contributions to the buildup of GHGs in the atmosphere vary greatly from country to country and depend heavily on the level of industrial and economic activity. Emissions from the United States account for approximately 17.4 percent of total global CO_2 emissions. As shown in Figure S-10, the U.S. transportation sector contributed 31 percent of total U.S. CO_2 emissions in 2009, with passenger cars and light trucks accounting for 65 percent of total U.S. CO_2 emissions from transportation. Therefore, 20 percent of total U.S. CO_2 emissions come from passenger cars and light trucks. From a global perspective, U.S. passenger cars and light trucks account for roughly 4 percent of total global CO_2 emissions.

Figure S-10. Contribution of Transportation to U.S. CO_2 Emissions and Proportion Attributable by Mode, 2009



HD = heavy-duty

Source: EPA (U.S. Environmental Protection Agency). 2011. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2009. Tables 2-14 and 2-15. Washington, D.C. EPA 430-R-11-005. 441 pgs. Available at: <http://www.epa.gov/climatechange/emissions/usinventoryreport.html> (Accessed: October 18, 2011).

Key Findings for Climate

The Proposed Action and alternatives would decrease the growth in global GHG emissions, resulting in reductions in the anticipated increases that are otherwise projected to occur in CO_2 concentrations, temperature, precipitation, and sea level. They would also, to a small degree, reduce the impacts and risks of climate change.

Note that under all alternatives analyzed in this EIS, growth in the number of passenger cars and light trucks in use throughout the United States, combined with assumed increases in their average use (annual VMT per vehicle), is projected to result in growth in total vehicle travel. This growth in travel outpaces improvements in fuel economy under Alternative 2 and the Preferred Alternative, resulting in projected increases in total fuel consumption by passenger cars and light trucks in the United States over the long term. Because CO_2 emissions are a direct consequence of fuel consumption, the same result is projected for total CO_2 emissions from passenger cars and light trucks. Under Alternative 4, increases in fuel economy result in projected fuel consumption and CO_2 emission levels through and beyond 2060 that are lower than present annual CO_2 emission levels.

NHTSA estimates that the proposed MY 2017–2025 CAFE standards would reduce fuel consumption and CO_2 emissions from what they would be in the absence of the standards (i.e., fuel consumption and CO_2 emissions under the No Action Alternative) (*see* Figures S-11-A and S-11-B).

The global emissions scenario used in the cumulative effects analysis (and described in Chapter 5 of this EIS) differs from the global emissions scenario used for the climate change modeling for direct and indirect effects. In the cumulative effects analysis, the Reference Case global emissions scenario used in the climate modeling analysis reflects reasonably foreseeable actions in global climate change policy; in contrast, the global emissions scenario used for the analysis of direct and indirect effects assumes that no significant global controls on GHG emissions are adopted. *See* Section 5.3.3.2.2 of this EIS for additional explanation of the cumulative effects methodology.

Estimates of GHG emissions and reductions (both direct and indirect effects and cumulative impacts) are presented below for each of the four alternatives. Climate effects such as mean global increase in surface temperature and sea-level rise are typically modeled to 2100 or longer due to the amount of time required for the climate system to show the effects of the GHG (or in this case, emission) reductions. This inertia primarily reflects the amount of time required for the ocean to warm in response to the increased radiative forcing.

The impacts of the Proposed Action and alternatives on global mean surface temperature, precipitation, or sea-level rise are small in relation to the expected changes associated with the emissions trajectories that assume that no significant global controls on GHG emissions are adopted. This is due primarily to the global and multi-sectoral nature of the climate problem. Although these effects are small, they occur on a global scale and are long-lived; therefore, in aggregate they can have large consequences for health and welfare.

Direct and Indirect Impacts

Greenhouse Gas Emissions

- Compared to the sum of projected U.S. passenger car and light truck CO_2 emissions of 166,500 million metric tons of carbon dioxide ($MMTCO_2$) under the No Action Alternative from 2017 through 2100 in Analysis A (139,500 $MMTCO_2$ in Analysis B), the action alternatives would reduce these emissions by 11 to 29 percent in Analysis A (6 to 22 percent in Analysis B) by 2100. Figures S-11-A and S-11-B show projected annual CO_2 emissions from passenger cars and light trucks under each alternative. As shown in the figure, emissions are highest under the No Action Alternative, while Alternatives 2 through 4 show increasing reductions in emissions compared to the No Action Alternative.
- Compared to total projected U.S. emissions of 7,193 $MMTCO_2$ under the No Action Alternative in 2100, the action alternatives are expected to reduce U.S total CO_2 emissions by between 3.7 and 9.2 percent in Analysis A (1.2 and 5.3 percent in Analysis B) in 2100.
- Compared to total global CO_2 emissions from all sources of 5,099,256 $MMTCO_2$ under the No Action Alternative from 2017 through 2100, the action alternatives are expected to

reduce total global CO_2 emissions by between 0.4 and 0.9 percent in Analysis A (0.2 and 0.6 percent in Analysis B) by 2100.

- The emission reductions under the alternatives are equivalent to the annual emissions from between 13.2 and 32.9 million passenger cars and light trucks in 2025 in Analysis A (12.7 and 32.7 in Analysis B), compared to the annual emissions that would occur under the No Action Alternative. Emission reductions in 2025 under the Preferred Alternative fall within this range, equating to annual emissions from 20.2 million passenger cars and light trucks in Analysis A (19.6 in Analysis B).

Figure S-11-A. Projected Annual CO_2 Emissions ($MMTCO_2$) from U.S. Passenger Cars and Light Trucks by Alternative, Direct and Indirect Impacts (Analysis A)

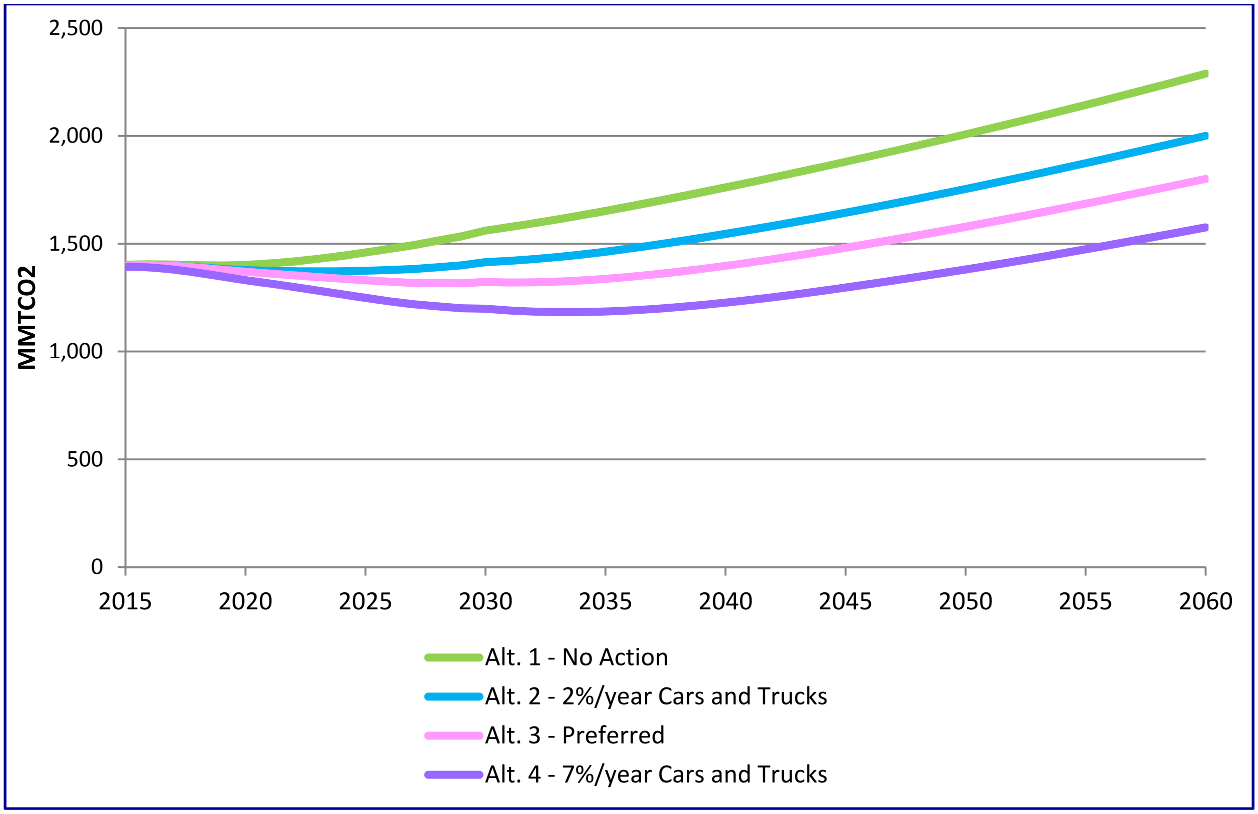
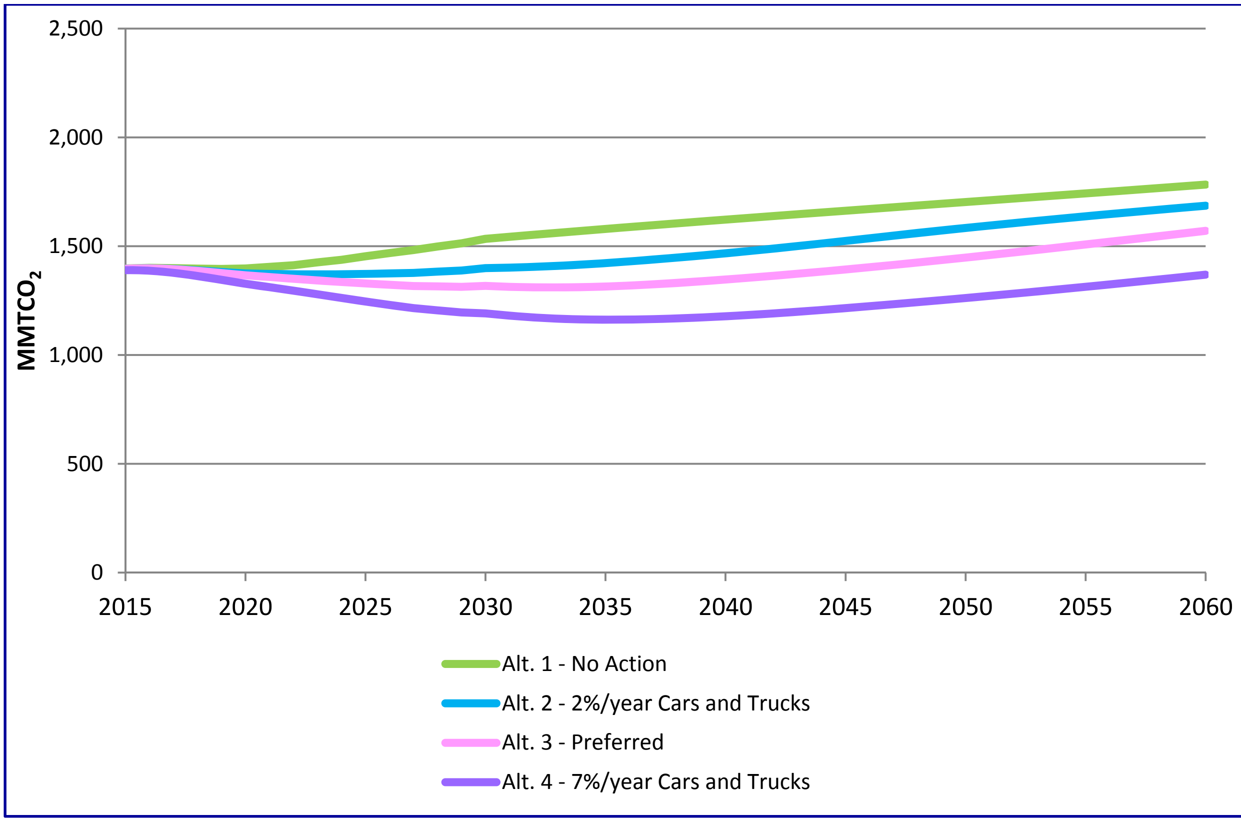


Figure S-11-B. Projected Annual CO_2 Emissions ($MMTCO_2$) from U.S. Passenger Cars and Light Trucks by Alternative, Direct and Indirect Impacts (Analysis B)



CO_2 Concentration, Global Mean Surface Temperature, Sea-level Rise, and Precipitation

CO_2 emissions affect the concentration of CO_2 in the atmosphere, which in turn affects global temperature, sea level, and precipitation patterns. For the analysis of direct and indirect effects, NHTSA used the GCAM Reference scenario to represent the Reference Case emissions scenario; that is, future global emissions assuming no additional climate policy. The impacts of the Proposed Action and alternatives on temperature, precipitation, or sea-level rise are small in absolute terms because the action alternatives result in a small proportional change to the emissions trajectories in the Reference Case scenario to which the alternatives were compared. Although these effects are small, they occur on a global scale and are long-lived.

- Estimated CO_2 concentrations in the atmosphere for 2100 would range from approximately 780 parts per million (ppm) in Analysis A (782 ppm in Analysis B) under Alternative 4 to approximately 785 ppm under the No Action Alternative, indicating a maximum atmospheric CO_2 reduction of approximately 5 ppm from the No Action Alternative in Analysis A (3 ppm in Analysis B). The Preferred Alternative would reduce global CO_2 concentrations by approximately 3.1 ppm in Analysis A (1.6 ppm in Analysis B) from CO_2 concentrations under the No Action Alternative.
- Global mean surface temperature is anticipated to increase by approximately 3.06 °C (5.51 °F) under the No Action Alternative by 2100. Implementing the most stringent alternative (Alternative 4) would reduce this projected temperature increase by 0.016 °C (0.029 °F) in

Analysis A (0.011 °C [0.020 °F] in Analysis B), while implementing Alternative 2 would reduce projected temperature increase by 0.006 °C (0.011 °F) in Analysis A (0.003 °C [0.005 °F] in Analysis B). Falling between these two levels, the Preferred Alternative would decrease projected temperature increase under the No Action Alternative by 0.011 °C (0.020 °F) in Analysis A (0.006 °C [0.011 °F] in Analysis B). Figures S-12-A and S-12-B demonstrate reductions in the growth of projected global mean temperature from each action alternative compared to the No Action Alternative.

- Projected sea-level rise in 2100 ranges from a high of 37.40 centimeters (14.72 inches) under the No Action Alternative to a low of 37.25 centimeters (14.66 inches) in Analysis A (37.29 centimeters [14.68 inches] in Analysis B) under Alternative 4. Therefore, the action alternatives would result in a maximum reduction of sea-level rise equal to 0.15 centimeter (0.06 inch) in Analysis A (0.11 centimeter [0.04 inch] in Analysis B) by 2100 from the level projected under the No Action Alternative. Sea-level rise under the Preferred Alternative would be reduced by 0.10 centimeter (0.039 inch) in Analysis A (0.06 centimeter [0.024 inch] in Analysis B) from the No Action Alternative.

Figure S-12-A. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative (Analysis A)

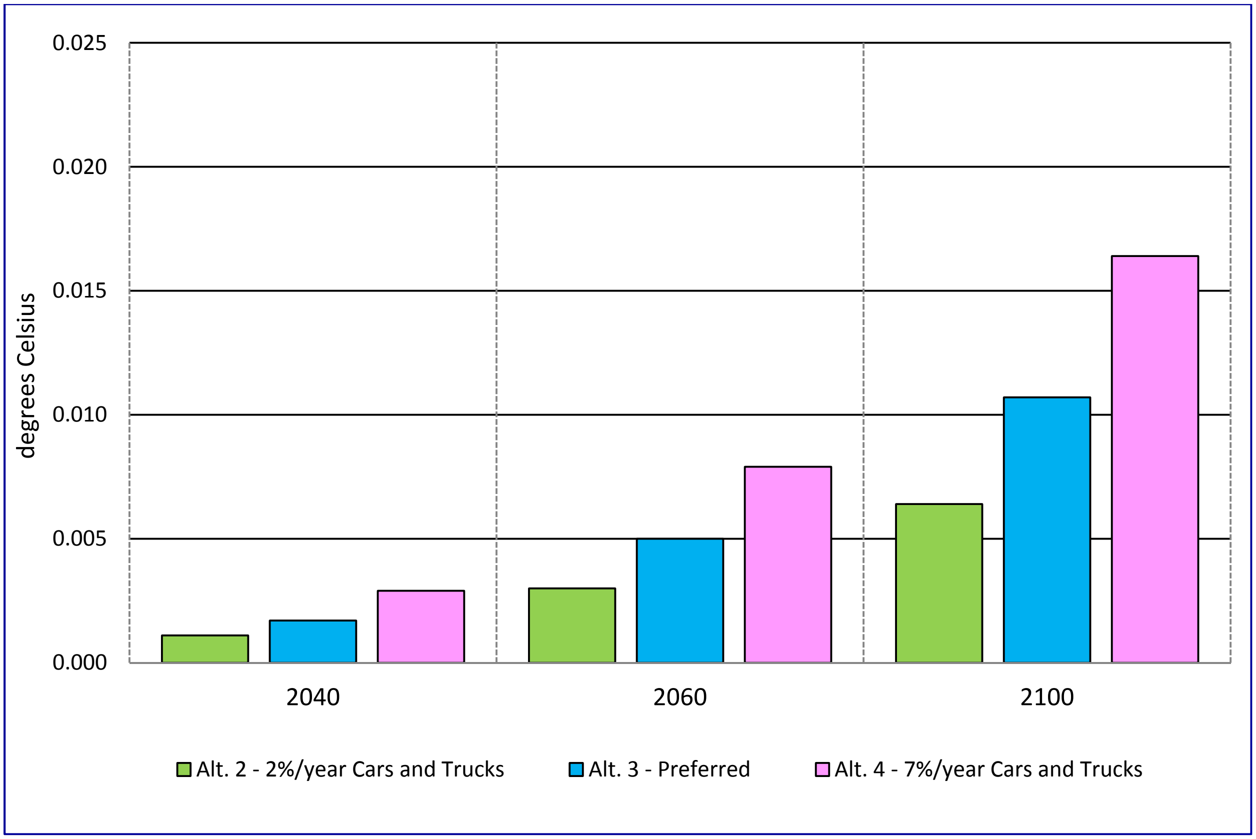
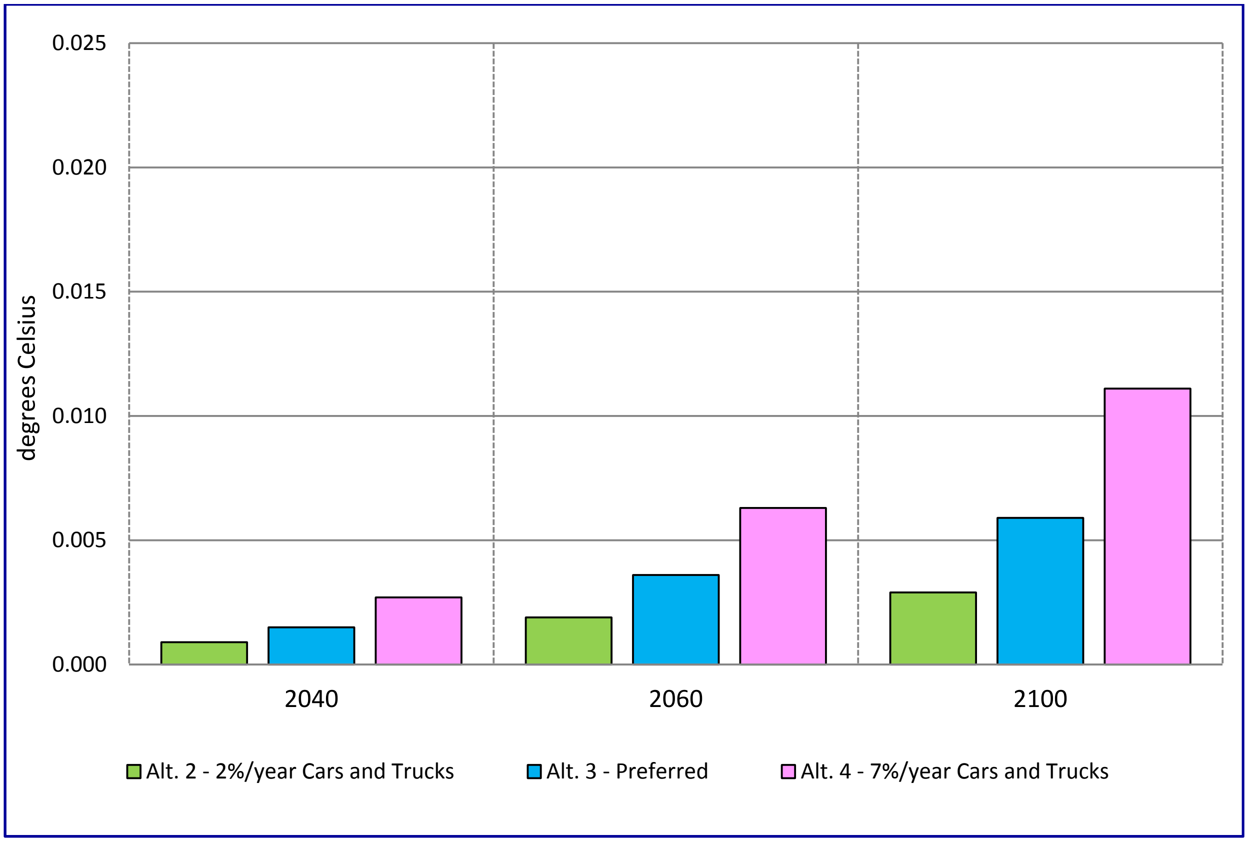


Figure S-12-B. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative (Analysis B)



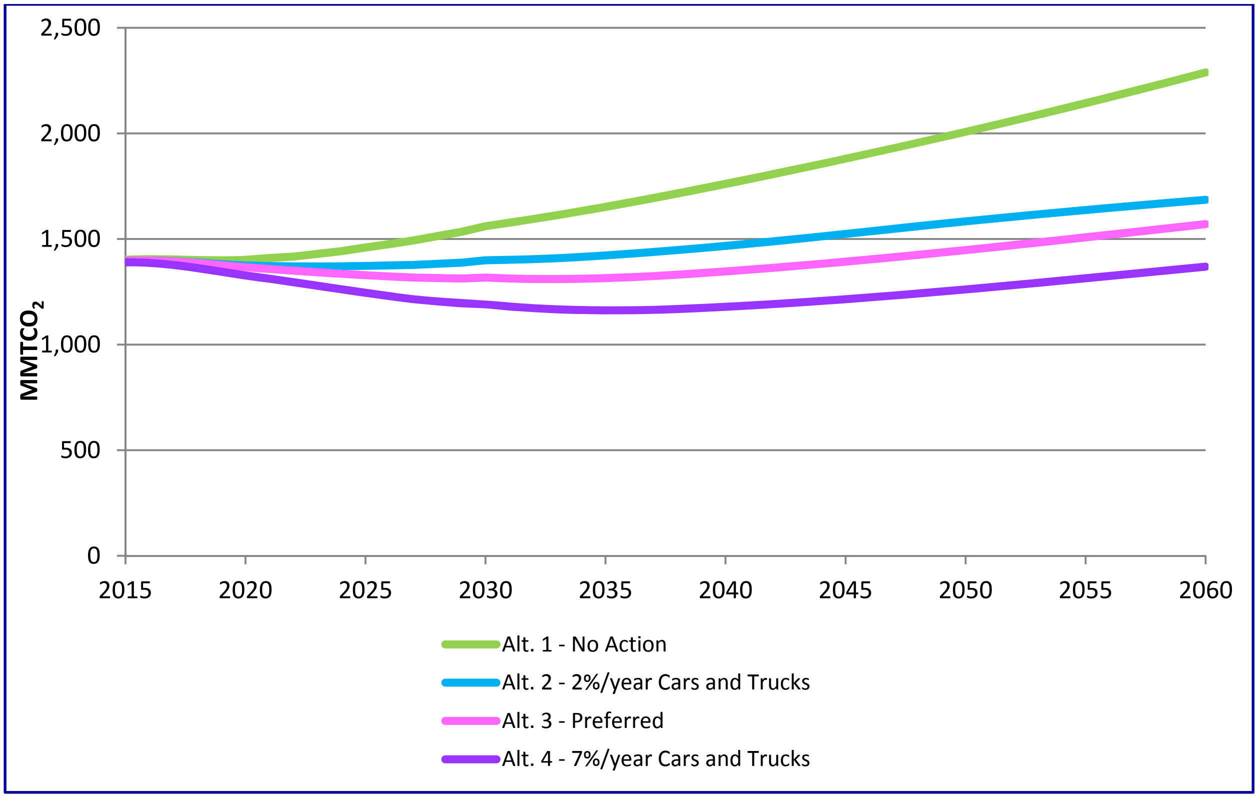
- Global mean precipitation is anticipated to increase by 4.50 percent by 2090 under the No Action Alternative. Under the action alternatives, this increase would be reduced by approximately 0.02 percent under Alternative 4 to 0.01 percent (0.00 percent in Analysis B) under Alternative 2. The Preferred Alternative would result in a 0.02 percent in Analysis A (0.01 percent in Analysis B) reduction in global mean precipitation increase, indicating a total increase of 4.48 percent in Analysis A (4.49 percent in Analysis B), instead of the 4.50 percent projected under the No Action Alternative.

Cumulative Impacts

Greenhouse Gas Emissions

- Projections of total emission reductions over the 2017 through 2100 period due to the proposed MY 2017–2025 CAFE standards and other reasonably foreseeable future actions (i.e., forecasted fuel efficiency increases resulting from market-driven demand) range from 35,600 to 58,300 $MMTCO_2$ as compared to the No Action Alternative. The action alternatives would reduce total passenger car and light truck emissions by between 21 and 35 percent by 2100. Figure S-13 shows projected annual CO_2 emissions from U.S. passenger cars and light trucks by alternative compared to the No Action Alternative.
- Compared to projected total global CO_2 emissions from all sources of 4,190,614 $MMTCO_2$ from 2017 through 2100, the incremental impact of this rulemaking is expected to reduce global CO_2 emissions by about 0.8 to 1.4 percent from their projected levels under the No Action Alternative.

Figure S-13. Projected Annual CO_2 Emissions ($MMTCO_2$) from U.S. Passenger Cars and Light Trucks by Alternative, Cumulative Impacts

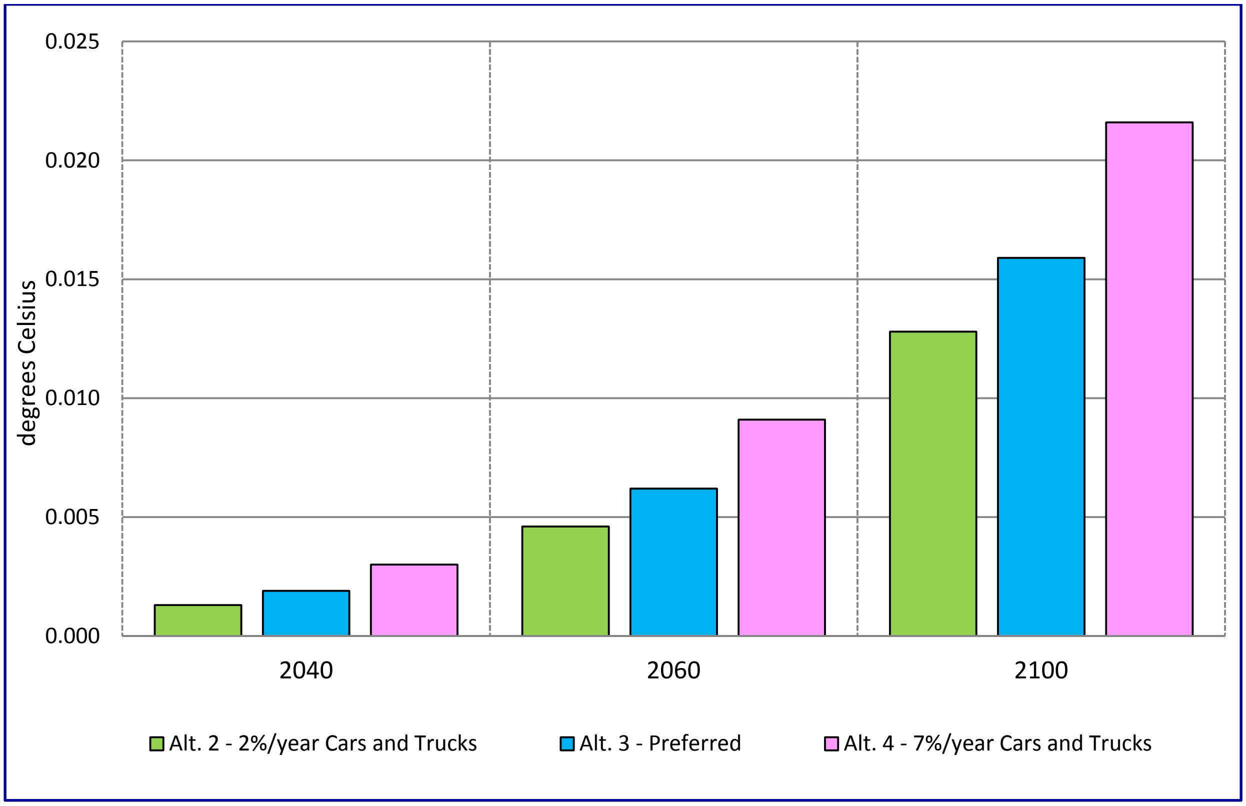


CO_2 Concentration, Global Mean Surface Temperature, Sea-Level Rise, and Precipitation

- Estimated atmospheric CO_2 concentrations for 2100 range from a low of 672.4 ppm under Alternative 4 to a high of 677.8 ppm under the No Action Alternative. The Preferred Alternative would result in CO_2 concentrations of 673.7 ppm, a reduction of 4.1 ppm from the No Action Alternative level.
- The reduction in global mean temperature increase for the action alternatives in relation to the No Action Alternative in 2100 ranges from a low of 0.013 °C (0.023 °F) to a high of 0.022 °C (0.040 °F). The Preferred Alternative would result in a reduction of 0.016 °C (0.029 °F) from the projected temperature increase of 2.564 °C (4.615 °F) under the No Action Alternative. Figure S-14 illustrates reductions in the increase of global mean temperature under each action alternative compared to the No Action Alternative.
- Projected sea-level rise in 2100 ranges from a high of 33.42 centimeters (13.15 inches) under the No Action Alternative to a low of 33.24 centimeters (13.08 inches) under Alternative 4, indicating a maximum reduction of sea-level rise equal to 0.18 centimeter (0.07 inch) by 2100 from the level that could occur under the No Action Alternative. Sea-level rise under the Preferred Alternative would be 33.29 centimeters (13.11 inches), a 0.13 centimeter (0.05 inch) reduction from the No Action Alternative level.

See Section 5.4 of this EIS for further details about the direct, indirect, and cumulative climate impacts.

Figure S-14. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative, Cumulative Impacts



Health, Societal, and Environmental Impacts of Climate Change

The action alternatives would reduce the impacts of climate change that would otherwise occur under the No Action Alternative. The magnitude of the changes in climate effects that would be produced by the most stringent alternative is roughly 3 to 5 ppm less of CO_2, a few hundredths of a degree difference in temperature increase, a small percentage change in the rate of precipitation increase, and 1 to 2 millimeters (0.040 to 0.080 inch) of sea-level rise. Although the projected reductions in CO_2 and climate effects are small compared to total projected future climate change, they are quantifiable, directionally consistent, and will contribute to reducing the risks associated with climate change. While NHTSA does quantify the reductions in monetized damages attributable to each action alternative (in the social cost of carbon analysis), many specific impacts on health, society, and the environment cannot be estimated quantitatively. Therefore, NHTSA provides a detailed discussion of the impacts of climate change on various resource sectors in Section 5.5 of this EIS. The changes in non-climate impacts (such as ocean acidification by CO_2) associated with the alternatives are discussed in this EIS in Section 5.6.

CHAPTER 1 PURPOSE AND NEED FOR THE PROPOSED ACTION

1.1 Introduction

The Energy Policy and Conservation Act of 1975 (EPCA)[1] established the Corporate Average Fuel Economy (CAFE) Program to reduce national energy consumption by increasing the fuel economy of passenger cars and light trucks. EPCA directs the Secretary of Transportation to set and implement fuel economy standards for passenger cars and light trucks sold in the United States.[2] The National Highway Traffic Safety Administration (NHTSA) is delegated responsibility for implementing EPCA fuel economy requirements assigned to the Secretary.[3]

In December 2007, Congress enacted the Energy Independence and Security Act of 2007 (EISA),[4] amending the EPCA CAFE program requirements by providing the U.S. Department of Transportation (DOT) additional rulemaking authority and responsibilities. Pursuant to EISA, NHTSA has issued final CAFE standards for model year (MY) 2011 passenger cars and light trucks,[5] as well as standards for MY 2012–2016 passenger cars and light trucks[6] and MY 2014–2018 medium- and heavy-duty vehicles in joint rulemakings with the Environmental Protection Agency (EPA).[7]

On May 21, 2010, President Obama issued a Presidential Memorandum entitled "Improving Energy Security, American Competitiveness and Job Creation, and Environmental Protection through a Transformation of our Nation's Fleet of Cars and Trucks."[8] This memorandum builds on the President's previous memorandum[9] from January 26, 2009, which established the Joint National Program and led to the NHTSA and EPA joint final rules establishing fuel economy and greenhouse gas (GHG) standards for MY 2012–2016 passenger cars and light trucks. The President's 2010 memorandum requested that NHTSA and EPA continue the Joint National Program by developing joint federal standards to improve fuel economy and reduce the GHG emissions of light-duty vehicles manufactured in MYs 2017–2025. The President requested that the agencies develop a Notice of Intent announcing plans for setting those standards by September 30, 2010, which would include "potential standards that could be practicably implemented nationally for the 2017–2025 model years and a schedule for setting those standards as expeditiously as possible, consistent with providing sufficient lead time to vehicle manufacturers."

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[1] EPCA was enacted for the purpose of serving the Nation's energy demands and promoting conservation methods when feasibly obtainable. EPCA is codified at 49 United States Code (U.S.C.) § 32901 et seq.

[2] 49 Code of Federal Regulations (CFR) § 1.50. In addition, EPA calculates the average fuel economy for each automobile manufacturer that sells vehicles in the United States. 49 U.S.C. § 32904.

[3] Accordingly, the Secretary of Transportation, DOT, and NHTSA are used interchangeably in this section of the Draft EIS.

[4] EISA amends and builds on EPCA by setting forth a comprehensive energy strategy for the twenty-first century, addressing renewable fuels and CAFE standards. Pub. L. No. 110-140, 121 Stat. 1492 (Dec. 19, 2007).

[5] NHTSA initially proposed standards for MY 2011–2015 passenger cars and light trucks (*see* Average Fuel Economy Standards, Passenger Cars and Light Trucks; Model Years 2011–2015. Notice of Proposed Rulemaking, 73 *Federal Register* [FR] 24352 [May 2, 2008]); however, on January 7, 2009, DOT announced that the Bush Administration would not issue the final rule for this rulemaking (*see* DOT 2009a). Instead, NHTSA issued a Final Rule only for MY 2011 passenger cars and light trucks (*see* Average Fuel Economy Standards Passenger Cars and Light Trucks Model Year 2011. Final Rule; Record of Decision, 74 FR 14196 [Mar. 30, 2009]).

[6] *See* Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, 75 FR 25324 (May 7, 2010).

[7] *See* Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, 76 FR 57106 (September 15, 2011).

[8] *See* White House 2010b.

[9] *See* White House 2009a.

On September 30, 2010, NHTSA and EPA issued a Notice of Intent that announced plans to develop a rulemaking setting stringent fuel economy and GHG emissions standards for light-duty vehicles for MY 2017 and beyond.[10] The notice was accompanied by an Interim Joint Technical Assessment Report, intended to inform the rulemaking process, which was developed by NHTSA, EPA, and the California Air Resources Board (CARB), in coordination with the U.S. Department of Energy (DOE). On December 8, 2010, the agencies published a Supplemental Notice of Intent highlighting many of the key comments received in response to the September Notice of Intent and the Interim Technical Assessment Report.[11] Over the next several months, the agencies, working with California, engaged in discussions with individual auto manufacturers, automotive suppliers, states, environmental groups, consumer groups, and the United Auto Workers, who all expressed support for a continuation of the National Program. These discussions and efforts focused on developing information that supported the underlying technical assessments that informed the proposed standards.[12] On May 10, 2011, NHTSA published a Notice of Intent to prepare an Environmental Impact Statement (EIS) for new CAFE Standards.[13] On July 29, 2011, NHTSA and EPA issued a final Supplemental Notice of Intent generally describing the agencies' expectations for the Notice of Proposed Rulemaking (NPRM),[14] including the intended levels of standards to be proposed and key program elements like compliance flexibilities and the mid-term evaluation.[15] That NPRM is being issued simultaneously with this Draft EIS.

This EIS has been developed pursuant to the National Environmental Policy Act (NEPA).[16] NEPA directs that federal agencies proposing "major federal actions significantly affecting the quality of the human environment" must, "to the fullest extent possible," prepare "a detailed statement" on the environmental impacts of the proposed action (including alternatives to the proposed action).[17] To inform its development of the proposed CAFE standards, NHTSA prepared this EIS which analyzes, discloses, and compares the potential environmental impacts of a reasonable range of action alternatives, including a proposed Preferred Alternative,[18] pursuant to Council on Environmental Quality (CEQ) NEPA implementing regulations, DOT Order 5610.1C, and NHTSA regulations.[19] This EIS analyzes direct, indirect, and cumulative impacts, and discusses impacts in proportion to their significance.

[10] *See* 2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards; Notice of Intent, 75 FR 62739 (Oct. 13, 2010).
[11] *See* 2017 and Later Model Year Light-Duty Vehicle GHG Emissions and CAFE Standards: Supplemental Notice of Intent, 75 FR 76337 (Dec. 8, 2010).
[12] *See* 2017–2025 Model Year Light-Duty Vehicle GHG Emissions and CAFE Standards: Supplemental Notice of Intent, 76 FR 48758 (Aug. 9, 2011).
[13] Notice of Intent to Prepare an Environmental Impact Statement for New Corporate Average Fuel Economy Standards, 76 FR 26996 (May 10, 2011).
[14] The NPRM will be available on the agency's fuel economy website (www.nhtsa.gov/fuel-economy) at the time of, or soon after, the issuance of this EIS.
[15] *See* 2017–2025 Model Year Light-Duty Vehicle GHG Emissions and CAFE Standards: Supplemental Notice of Intent, 76 FR 48758 (Aug. 9, 2011).
[16] 42 U.S.C. §§ 4321–4347.
[17] 42 U.S.C. § 4332.
[18] On July 29, 2011, President Obama announced aspects of the agency's proposed Preferred Alternative (White House 2011a). On that day, a number of stakeholders signed "Letters of Commitment" in support of the program but recognizing that the National Program will be subject to full notice-and-comment rulemaking, which provides all interested parties "the right to participate fully, comment, and submit information, the results of which are not pre-determined but depend upon processes set by law" (NHTSA 2011a). The preparation of this EIS is part of this process, and the agency's final decision will be informed by the Final EIS.
[19] NEPA is codified at 42 U.S.C. §§ 4321–4347. CEQ NEPA implementing regulations are codified at 40 CFR Parts 1500–1508, and NHTSA's NEPA implementing regulations are codified at 49 CFR Part 520.

1.2 Purpose and Need

NEPA requires that agencies develop alternatives to a proposed action based on the action's purpose and need. The purpose and need statement explains why the action is needed, describes the action's intended purpose, and serves as the basis for developing the range of alternatives to be considered in the NEPA analysis.[20] In accordance with EPCA, as amended by EISA, one purpose of the Joint Rulemaking is to establish MY 2017–2025 CAFE Standards at "the maximum feasible average fuel economy level that the Secretary of Transportation decides the manufacturers can achieve in that model year."[21] When determining the maximum feasible levels that manufacturers can achieve in each model year, EPCA requires that the Secretary of Transportation consider the four statutory factors of "technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy."[22] In addition, the agency has the authority to – and traditionally does – consider other relevant factors, such as the effect of the CAFE standards on motor vehicle safety.[23]

NHTSA has defined these considerations as follows:[24]

- "Technological feasibility" refers to whether a particular method of improving fuel economy can be available for commercial application in the model year for which a standard is being established.
- "Economic practicability" refers to whether a standard is one within the financial capability of the industry, but not so stringent as to lead to adverse economic consequences, such as significant job losses or unreasonable elimination of consumer choice.
- "The effect of other motor vehicle standards of the Government on fuel economy," involves an analysis of the effects of compliance with emission,[25] safety, noise, or damageability standards on fuel economy capability and therefore on average fuel economy.
- "The need of the United States to conserve energy" means the consumer cost, national balance of payments, environmental, and foreign policy implications of the Nation's need for large quantities of petroleum, especially imported petroleum.

Under EISA, NHTSA must establish separate standards for passenger cars and light trucks for each model year, subject to two principal requirements. First, the standards are subject to a minimum requirement regarding stringency – they must be set at levels high enough to ensure that the combined U.S. passenger car and light truck fleet achieves an average fuel economy level of not less than 35 miles per gallon (mpg) not later than MY 2020.[26] Second, EPCA requires that the agency establish separate average fuel economy standards for all new passenger cars and light trucks at the maximum feasible average fuel economy level that the Secretary of Transportation decides the manufacturers can achieve in that model year.[27]

[20] 40 CFR § 1502.13.
[21] 49 U.S.C. § 32902(a).
[22] 49 U.S.C. §§ 32902(a), 32902(f).
[23] *See*, *e.g.*, *Competitive Enterprise Inst. v. NHTSA*, 956 F.2d 321, 322 (D.C. Cir. 1992) (citing *Competitive Enterprise Inst. v. NHTSA*, 901 F.2d 107, 120 n.11 (D.C. Cir. 1990)); Average Fuel Economy Standards, Passenger Cars and Light Trucks; Model Years 2011–2015, Notice of Proposed Rulemaking, 73 FR 24352 (May 2, 2008).
[24] Final Rule, Record of Decision, Average Fuel Economy Standards Passenger Cars and Light Trucks Model Year 2011, 74 FR 14196 (Mar. 30, 2009).
[25] In the case of emission standards, this includes standards adopted by the Federal Government and can include standards adopted by the states, because in certain circumstances, the Clean Air Act (CAA) allows states to adopt and enforce state standards different from the federal standards.
[26] 49 U.S.C. § 32902(b)(2)(A).
[27] 49 U.S.C. § 32902(a).

Standards must also be "based on one or more vehicle attributes related to fuel economy," and "expressed in the form of a mathematical function."[28] In addition, EISA requires that the CAFE standards for passenger cars and light trucks increase ratably in each model year between MY 2011 and MY 2020.[29] Finally, NHTSA is also guided by President Obama's memorandum to DOT on May 21, 2010, as described in Section 1.1. This memorandum further outlines the purpose of and need for the Proposed Action.

1.3 National Environmental Policy Act and Joint Rulemaking Process

Concurrent with this Draft EIS, NHTSA and EPA are announcing joint proposed rules to establish CAFE standards and GHG emission standards for MY 2017–2025 light-duty vehicles. The joint rules would address the urgent and closely intertwined challenges of energy independence and security and climate change by proposing a strong and coordinated federal fuel economy and GHG program for passenger cars, light-duty trucks, and medium-duty passenger vehicles (hereinafter, "passenger cars and light trucks" or "light-duty vehicles"), referred to as the National Program. The proposed rules can achieve substantial improvements in fuel economy and reductions of GHG emissions from the light-duty vehicle sector. This proposal builds on the first phase of the National Program, established by a joint final rule issued by NHTSA and EPA in April 2010, in which NHTSA set CAFE standards and EPA set GHG emission standards for MY 2012–2016 passenger cars and light trucks.[30]

The National Program holds the promise of delivering additional environmental and energy benefits, cost savings, and administrative efficiencies nationwide that might not be available under a less coordinated approach. The proposed National Program also offers the prospect of regulatory convergence by making it possible for the standards of two federal agencies and the standards of California and other states to act in a unified way to provide these benefits. This would allow automakers to produce and sell a single light-duty fleet nationally. Therefore, the approach mitigates the additional costs manufacturers would otherwise face in having to comply with multiple sets of federal and state standards.

1.3.1 Building Blocks of the National Program

The National Program is both needed and possible because the relationship between improving fuel economy and reducing carbon dioxide (CO_2) tailpipe emissions is a very direct and close one. The amount of CO_2 emissions is essentially constant per gallon combusted of a given type of fuel. Therefore, the more fuel efficient a vehicle, the less fuel it burns to travel a given distance. The less fuel it burns, the less CO_2 it emits in traveling that distance. While there are emission control technologies that reduce the pollutants (e.g., carbon monoxide) produced by imperfect combustion of fuel by capturing or destroying them, there is no such technology for CO_2. Further, while some of those pollutants can also be reduced by achieving a more complete combustion of fuel, doing so only increases the tailpipe emissions of CO_2. Therefore, the same technologies address these twin problems (those that reduce fuel consumption and thereby reduce CO_2 emissions).

[28] 49 U.S.C. § 32902(b)(3)(A).
[29] 49 U.S.C. § 32902(b)(2)(C). NHTSA interprets this requirement, in combination with the requirement to set the standards for each model year at the level determined to be the maximum feasible level for that model year, to mean that the annual increases should not be disproportionately large or small in relation to each other.
[30] Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, 75 FR 25324 (May 7, 2010).

1.3.1.1 DOT's Corporate Average Fuel Economy Program

In 1975, Congress enacted EPCA, mandating that NHTSA establish and implement a regulatory program for motor vehicle fuel economy to meet the various facets of the need to conserve energy, including those with energy independence and security, environmental, and foreign policy implications. Fuel economy gains since 1975, due both to standards and market factors, have resulted in saving billions of barrels of oil and avoiding billions of metric tons of CO_2 emissions. In December 2007, Congress enacted EISA, amending EPCA to require substantial, continuing increases in fuel economy standards.

To verify compliance with the CAFE standards, EPA determines fuel economy by measuring the amount of CO_2 and other carbon compounds emitted from the tailpipe. The carbon content of the test fuel is then used to calculate the amount of fuel that had to be consumed per mile to produce that amount of CO_2. Finally, that fuel consumption figure is converted into an mpg figure. CAFE standards do not address the 5 to 8 percent of GHG emissions that are not CO_2 (i.e., nitrous oxide, methane, and hydrofluorocarbons [HFCs]).

1.3.1.2 EPA's Greenhouse Gas Standards for Light-Duty Vehicles

Under the CAA, EPA is responsible for addressing air pollutants from motor vehicles. In 2007, the U.S. Supreme Court issued *Massachusetts v. Environmental Protection Agency*,[31] a case involving a 2003 EPA order denying a petition for rulemaking to regulate GHG emissions from motor vehicles under CAA Section 202(a).[32] The Court held that GHGs were air pollutants for purposes of the CAA and further held that the EPA Administrator must determine whether emissions from new motor vehicles cause or contribute to air pollution that might reasonably be anticipated to endanger public health or welfare, or whether the science is too uncertain to make a reasoned decision. The Court further ruled that, in making these decisions, the EPA Administrator is required to follow the language of CAA Section 202(a). The Court rejected the argument that EPA cannot regulate CO_2 from motor vehicles because to do so would de facto tighten fuel economy standards, authority over which Congress has assigned to DOT. The Court held that the fact "that DOT sets mileage standards in no way licenses EPA to shirk its environmental responsibilities. EPA has been charged with protecting the public's 'health' and 'welfare', a statutory obligation wholly independent of DOT's mandate to promote energy efficiency." The Court concluded that "[t]he two obligations may overlap, but there is no reason to think the two agencies cannot both administer their obligations and yet avoid inconsistency."[33]

EPA has since found that emissions of GHGs from new motor vehicles and motor vehicle engines do cause or contribute to air pollution that can reasonably be anticipated to endanger public health and welfare.[34] The joint NHTSA-EPA Final Rule for MY 2012–2016 passenger cars and light trucks issued in 2010, as well as the current proposal, represent EPA's response to the U.S. Supreme Court decision.[35]

[31] 549 U.S. 497 (2007).
[32] *See* Notice of Denial of Petition for Rulemaking, Control of Emissions From New Highway Vehicles and Engines, 68 FR 52922 (September 8, 2003).
[33] 549 U.S. at 531-32. For more information on *Massachusetts v. Environmental Protection Agency, see* the July 30, 2008, Advance Notice of Proposed Rulemaking, Regulating Greenhouse Gas Emissions under the Clean Air Act, 73 FR 44354 at 44397. This includes a comprehensive discussion of the litigation history, the U.S. Supreme Court findings, and subsequent actions undertaken by the Bush Administration and EPA from 2007 through 2008 in response to the Supreme Court remand.
[34] Final Rule, Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 FR 66496 (Dec. 15, 2009).
[35] *See* Light-Duty Vehicles Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, 75 FR 25324 (May 7, 2010).

1.3.1.3 California Air Resources Board Greenhouse Gas Program

The California Air Resources Board (CARB) sets emissions standards for motor vehicles for the State of California. In 2004, CARB approved standards regulating the emission of CO_2 and other GHGs for MY 2009–2016 light-duty vehicles. The California standards apply to each model year from 2009 through 2016 and require maximum emissions for passenger cars and some light trucks of 323 grams per mile CO_2-equivalent (CO_2e) in 2009, increasing in stringency to 205 grams per mile in 2016, and 439 grams per mile for light trucks in 2009, increasing in stringency to 332 grams per mile in 2016.[36]

On June 30, 2009, EPA granted California's request for a waiver of preemption under the CAA.[37] The waiver allowed California, and the 14 other states (as well as the District of Columbia) that had adopted the California standards, to implement the standards beginning with MY 2009. In February 2010, CARB revised its program so that for MYs 2012–2016 manufacturers may elect to comply with the California standards by demonstrating compliance with the EPA GHG standards.[38] On June 14, 2011, EPA confirmed that CARB's amendments to its motor vehicle emissions standards are within the scope of the existing waiver for California's GHG emissions standards for 2009 and later, thereby allowing continued implementation of the California emission standards in applicable states.[39]

In a letter to Secretary of Transportation Ray LaHood and EPA Administrator Lisa Jackson dated July 28, 2011, CARB wrote that "California welcomes the opportunity to be a partner in helping to advance a continued, harmonized National Program" for model years 2017 and beyond.[40]

1.3.2 Proposed Action

For this EIS, NHTSA's Proposed Action is to set fuel economy standards for passenger cars and light trucks for MYs 2017–2025, in accordance with EPCA, as amended by EISA. Because in any single rulemaking under EPCA, standards may be established for not more than 5 model years,[41] NHTSA intends to issue conditional standards for MYs 2022–2025. The CAFE standards for MYs 2022–2025 will be determined with finality in a subsequent, de novo notice and comment rulemaking conducted in full compliance with 49 U.S.C. § 32902 and other applicable law. Because these two NHTSA actions are being proposed together to increase the efficiency of the light-duty fleet, and because they are part of a joint NHTSA/EPA rulemaking for a coordinated National Program covering MYs 2017–2025, this EIS addresses the potential environmental impacts of the proposed alternatives for the full MY 2017–2025 period together, notwithstanding the provision for a mid-term evaluation that might ultimately result in final standards for MYs 2022–2025 that are either the same as or different from the conditional standards developed as part of this rulemaking, depending on the information before the agency and the agency's balancing of the factors at the time of that future rulemaking to determine the maximum feasible levels.

[36] California Code of Regulations, Title 13 § 1961.1(a)(1).
[37] *See* California State Motor Vehicle Pollution Control Standards, Notice of Decision Granting a Waiver of Clean Air Act Preemption for California's 2009 and Subsequent Model Year Greenhouse Gas Emission Standards for New Motor Vehicles, 74 FR 32744 (July 8, 2009).
[38] *See* California Code of Regulations, Title 13 § 1961.1(a)(1)(A)(ii).
[39] California State Motor Vehicle Pollution Control Standards; Within-the-Scope Determination for Amendments to California's Motor Vehicle Greenhouse Gas Regulations; Notice of Decision, 76 FR 34693 (June 14, 2011).
[40] *See* CARB 2011*.*
[41] 49 U.S.C. § 32902(b)(3)(B).

1.3.2.1 Level of the Standards

NHTSA and EPA are proposing separate but harmonized sets of standards for passenger cars and light trucks under each agency's respective statutory authority. The proposed standards for both agencies begin with MY 2017, with standards increasing in stringency through MY 2025. Under NHTSA's Proposed Action, the agency estimates that the combined average required fuel economy level will be 40.9 mpg in MY 2021 and 49.6 mpg in MY 2025.[42] Under EPA's proposal, light-duty vehicles would be required to meet an estimated combined average emissions level of 163 grams per mile of CO_2 in MY 2025.

Under EPCA, EPA has the authority to measure and calculate manufacturers' average fuel economy for the CAFE program. For the first time, EPA's proposed rule would allow manufacturers to account for improvements to air conditioner efficiency that have a measurable impact on real-world fuel economy in the calculation of fuel economy for CAFE compliance. Because such improvements are available for compliance, NHTSA's proposed standards (like EPA's GHG standards) assume manufacturers will improve air conditioner efficiency to meet those standards. This aspect of the agencies' proposal is discussed in more detail in the NPRM.

The standards are "harmonized" even though they are not identical and reflect different rates of increase in stringency for the different programs. The difference is rooted in differences in NHTSA's and EPA's respective statutory authorities. Whereas NHTSA is regulating vehicle fuel economy, EPA is regulating GHGs, which include HFC-based refrigerants used in air conditioner systems that can leak from vehicles during normal vehicle operation or at end-of-life. Under the proposed GHG standards, EPA expects manufacturers to take advantage of the option to generate CO_2e credits by reducing HFC leakage from vehicle air conditioner systems. Accordingly, the level of EPA's proposed standards reflects the expected amounts of HFC leakage improvement. Air-conditioner refrigerant *leakage* improvements, unlike the air conditioner *efficiency* improvements described above, have no impact on fuel economy. Therefore, NHTSA does not consider improvements in air conditioner systems related to refrigerant leakage for purposes of CAFE compliance, and NHTSA's proposed CAFE standards do not include such improvements or their mpg equivalents. The agencies' joint proposals are still harmonized because they allow industry to build a single national fleet that will satisfy both CAFE requirements under EPCA, as amended by EISA, and GHG emissions requirements under the CAA.

1.3.2.2 Form of the Standards

In this rulemaking, NHTSA and EPA again propose attribute-based standards for passenger cars and light trucks. NHTSA adopted an attribute standard based on vehicle footprint in its Reformed CAFE program for light trucks for MYs 2008–2011,[43] and extended this approach to passenger cars in the CAFE rule for MY 2011, as required by EISA.[44] NHTSA and EPA also

[42] Here and throughout this document, when NHTSA refers to the proposed MY 2022–2025 standards as "required," NHTSA recognizes that they will not be made required in this rulemaking, but could be required in a subsequent de novo rulemaking. However, because the MY 2017–2021 standards and the MY 2022–2025 conditional standards are being proposed together to increase the efficiency of the light-duty fleet, and because they are part of a joint NHTSA/EPA rulemaking for a coordinated National Program covering MYs 2017–2025, NHTSA assumes solely for purposes of this analysis that that the proposed conditional standards will be finalized and therefore required.
[43] Final Rule, Average Fuel Economy Standards for Light Trucks Model Years 2008–2011, 71 FR 17566 (Apr. 6, 2006).
[44] Final Rule, Record of Decision, Average Fuel Economy Standards Passenger Cars and Light Trucks Model Year 2011, 74 FR 14196 (Mar. 30, 2009).

used an attribute standard for the joint rule establishing standards for MY 2012–2016 passenger cars and light trucks.[45]

Under an attribute-based standard, each vehicle model has a performance target (fuel economy for the CAFE standards; CO_2 grams per mile for the GHG emissions standards), the level of which depends on the vehicle's attribute. For this rulemaking, along with the rulemakings for previous model years, NHTSA and EPA proposed vehicle footprint as the attribute for CAFE and GHG standards. Vehicle footprint is one measure of vehicle size and is defined as a vehicle's wheelbase multiplied by the vehicle's track width. The agencies believe that the footprint attribute is the most appropriate attribute on which to base the standards under consideration, as discussed in the NPRM and the Interim Joint Technical Assessment Report (EPA, NHTSA, and CARB 2010). As required by EPCA/EISA, each manufacturer would have separate footprint-based standards for cars and for trucks. Generally, larger vehicles (i.e., vehicles with larger footprints) would be subject to less stringent standards (i.e., higher CO_2 gram-per-mile standards and lower CAFE standards) than smaller vehicles. This is because, typically, smaller vehicles are more capable of achieving higher standards than larger vehicles.

After using vehicle footprint as the attribute to determine each specific vehicle model performance target, the manufacturers' fleet average performance is then determined by the production-weighted[46] average (for CAFE, harmonic average) of those targets. The manufacturer's ultimate compliance obligation is based on that average; no particular vehicle is required to meet or exceed its particular target mpg level, but the fleet on average must meet or exceed the average required level to comply.

Therefore, although a manufacturer's fleet average standard could be estimated throughout the model year based on projected production volume of its vehicle fleet, the standard with which the manufacturer must comply would be based on its final model year production figures. A manufacturer's calculation of fleet average emissions at the end of the model year would therefore be based on the production-weighted average (for CAFE, harmonic average) emissions of each model in its fleet.

NHTSA and EPA include a full discussion of the equations and coefficients that define the passenger car and light truck curves proposed for each model year by each agency in the NPRM.

1.3.2.3 Program Flexibilities for Achieving Compliance

As with previous model year rules, NHTSA and EPA have proposed standards intended to provide manufacturers compliance flexibility, especially in the early years of the program. The flexibility provisions the agencies propose for this rulemaking, and that are discussed in the NPRM, fall under the following categories: CO_2/CAFE Credits Generated Based on Fleet Average Over-Compliance; Air Conditioning Improvement Credits/Fuel Economy Value Increases; Off-Cycle Credits/Fuel Economy Value Increases; Incentives for Electric Vehicles, Plug-in Hybrid Electric Vehicles, and Fuel Cell Vehicles; and Incentives for "Game Changing" Technologies Performance for Full-Size Pickup Truck including Hybridization. Some of these flexibilities will be available to manufacturers in aiding compliance under both sets of standards, but some flexibilities, such as air conditioning credits related to refrigerant leakage, will only be available under the EPA standard due to differences between the CAFE and CAA legal authorities.

[45] *See* Chapter 2 of NHTSA 2010a.
[46] Production for sale in the United States.

1.3.2.4 Compliance

In the NPRM, NHTSA and EPA noted that the MY 2012–2016 final rules established detailed and comprehensive regulatory provisions for compliance and enforcement under the CAFE and GHG emissions standards programs. These provisions remain in place for model years beyond MY 2016 without additional action by the agencies, and the agencies do not propose any significant modifications to them. In the MY 2012–2016 final rule, NHTSA and EPA established a program that recognizes, and replicates as closely as possible, the compliance protocols associated with the existing CAA Tier 2 vehicle emission standards and with earlier model year CAFE standards. The certification, testing, reporting, and associated compliance activities established for the GHG program closely track those in previously existing programs and are therefore familiar to manufacturers. EPA already oversees testing, collects and processes test data, and performs calculations to determine compliance with both CAFE and CAA standards. Under this coordinated approach, the compliance mechanisms for both programs are consistent and not duplicative. EPA also applies the CAA authorities applicable to its separate in-use requirements in this program.

The compliance approach allows manufacturers to satisfy the GHG program requirements in the same general way they comply with previously existing applicable CAA and CAFE requirements. Manufacturers will demonstrate compliance on a fleet-average basis at the end of each model year, allowing model-level testing to continue throughout the year, as is the current practice for CAFE determinations. The compliance program design includes a single set of manufacturer reporting requirements and relies on a single set of underlying data. This approach still allows each agency to assess compliance with its respective program under its respective statutory authority. The program also addresses EPA enforcement in cases of noncompliance.

1.4 Cooperating Agencies

Section 1501.6 of the CEQ NEPA implementing regulations emphasizes agency cooperation early in the NEPA process and authorizes a lead agency (in this case, NHTSA) to request the assistance of other agencies that either have jurisdiction by law or have special expertise regarding issues considered in an EIS.[47] On September 26, 2011, NHTSA invited EPA to be a cooperating agency pursuant to CEQ regulations because of its special expertise in the areas of climate change and air quality. In its invitation letter, NHTSA suggested that EPA's role in the development of the EIS could include the following:

- Providing input on determining the significant issues to be analyzed in the EIS from climate change and air quality perspectives.
- Helping NHTSA "identify and eliminate from detailed study the issues which are not significant or which have been covered by prior environmental review (§ 1506.3), narrowing the discussion of these issues in the statement to a brief presentation of why they will not have a significant effect on the human environment or providing a reference to their coverage elsewhere." 40 CFR § 1501.7(a)(3).
- Participating in coordination meetings, as appropriate.
- Reviewing and commenting on the Draft EIS and the Final EIS before publication.

[47] 40 CFR § 1501.6.

On October 7, 2011, EPA accepted NHTSA's invitation and agreed to become a cooperating agency.[48] EPA personnel have participated in technical discussions regarding analyses for the proposal and were asked to review and comment on draft sections and the draft final version of the Draft EIS.

1.5 Public Review and Comment

As described above, on May 10, 2011, NHTSA published a Notice of Intent to prepare an EIS for the new CAFE standards for MY 2017–2025 passenger cars and light trucks.[49] The notice described the statutory requirements for the standards, provided initial information about the NEPA process, and initiated scoping[50] by requesting public input on the scope of the environmental analysis. Two important purposes of scoping are (1) identifying the substantial environmental issues that merit in-depth analysis in the EIS and (2) identifying and eliminating from detailed analysis the environmental issues that are not substantial and therefore require only brief discussion in the EIS.[51] Scoping should "deemphasize insignificant issues, narrowing the scope of the environmental impact statement process accordingly."[52] Consistent with NEPA and its implementing regulations, NHTSA subsequently mailed the notice to:

- Contacts at federal agencies with jurisdiction by law or special expertise regarding the environmental impacts involved, or authorized to develop and enforce environmental standards, including other agencies within DOT
- The Governors of every state and U.S. territory
- Organizations representing state and local governments
- Native American tribes and tribal organizations
- Individuals and contacts at other stakeholder organizations that NHTSA reasonably expects to be interested in the NEPA analysis for the new CAFE standards, including advocacy, industry, and other organizations.

1.5.1 Scoping Comments

NHTSA received responses to its scoping notice from one state agency, eight advocacy groups, five industry organizations, and four individuals. In addition to these comments, NHTSA received over 10,000 comments from supporters of the National Wildlife Federation Action Fund, mostly as form letters, and a comment letter from the Union of Concerned Scientists enclosing over 600 individual comments from its supporters. This section summarizes these scoping comments.

To view the full comment letters, visit www.regulations.gov and enter the search term "NHTSA-2011-0056," which corresponds to the docket number for this EIS. All comments will be displayed in the search results.

[48] While NHTSA is required to complete an EIS for this rulemaking under NEPA, EPA does not have the same statutory obligation. EPA actions under the CAA, including EPA's proposed vehicle GHG emission standards for light-duty vehicles under the Joint Rulemaking, are not subject to NEPA requirements. *See* Section 7(c) of the Energy Supply and Environmental Coordination Act of 1974 (15 U.S.C. § 793(c)(1)). EPA is completing its own environmental review of the proposed rule as part of a separate Regulatory Impact Analysis (RIA) for this rulemaking.
[49] Notice of Intent to Prepare an Environmental Impact Statement for New Corporate Average Fuel Economy Standards, 76 FR 26996 (May 10, 2011).
[50] Scoping, as defined under NEPA, is an early and open process for determining the scope of issues to be addressed in an EIS and for identifying the significant issues related to a proposed action. *See* 40 CFR § 1501.7.
[51] *See* 40 CFR §§ 1500.4(g) and 1501.7(a).
[52] 40 CFR § 1500.4(g).

Several commenters referenced or submitted studies, research, and other information supporting or in addition to their comments. NHTSA has carefully reviewed these submissions for inclusion in this EIS.

Some comments went beyond the traditional scoping inquiry related to the nature and content of the environmental analysis. Several comments expressed preference for a particular regulatory alternative or raised concerns about costs or economic effects on vehicle and other industries. Comments of this nature are more directly relevant to the NHTSA rulemaking than they are to determining the scope of the environmental analysis, identifying impacts that should be analyzed in-depth, or identifying impacts that require less detailed consideration. NHTSA will evaluate these comments in light of all other substantive comments received before making a final decision and issuing the final rule. Although NHTSA acknowledges that there are some areas of overlap, the comments summarized below focus more specifically on the scoping process.

1.5.1.1 Government Agencies

The Michigan Department of Transportation (MDOT) was the only government agency that provided scoping comments (Docket No. NHTSA-2011-0056-0807). MDOT expressed overall support for the program but warned of the potential burden that increased fuel economy standards could have on the economy, in particular the impact increased standards could have on jobs, the automotive industry, and on the social and man-made environment. MDOT suggested that NHTSA and EPA work closely with vehicle manufacturers to develop feasible standards. MDOT also suggested that the agencies examine the impact that more stringent fuel economy standards have on the tax base, including the Highway Trust Fund, which supports investments in transportation infrastructure. MDOT advised that increases in fuel economy reduce the sustainability of the current tax structure, and that alternatives to motor fuel taxes should be considered in order to maintain funding for road construction and maintenance that would enable state transportation agencies to provide a safe and environmentally sustainable transportation system. Similarly, MDOT recommended that this EIS attempt to estimate the change in costs associated with reduced investment in transportation infrastructure.

Both NHTSA's Preliminary RIA and the NPRM address NHTSA's analysis of impacts on the economy and jobs, as well as how such considerations were accounted for in developing the Proposed Action. NHTSA and EPA have engaged stakeholders, such as vehicle manufacturers, in developing information that supported the underlying technical assessments that informed the proposed standards. Although NHTSA has analyzed impacts to the social and man-made environment in this EIS, it has not analyzed the impact of fuel economy standards on the tax base, including the Highway Trust Fund. The agency believes such effects are not environmental in nature and therefore not appropriate topics to address in this EIS.[53]

1.5.1.2 Advocacy Groups

NHTSA received letters from eight advocacy groups, including the National Wildlife Federation Action Fund (Docket No. NHTSA-2011-0056-0798); the Environmental Defense Fund (EDF) (Docket No. NHTSA-2011-0056-0827 and NHTSA-2011-0056-0943); the Sierra Club, Safe Climate Campaign, and Environment America (Docket No. NHTSA-2011-0056-0765); the Center for Biological Diversity (CBD) (Docket No. NHTSA-2011-0056-0775); the Natural Resources Defense Council (NRDC) (Docket No. NHTSA-2011-0056-0782); and the Union of

[53] *Monarch Chem. Works, Inc. v. Exon*, 466 F. Supp. 639, 652 (D. Neb. 1979), *aff'd on other grounds sub nom. Monarch Chem. Works, Inc. v. Thone*, 604 F.2d 1083 (8th Cir. 1979) ("The Court does not believe that the impact of a federal action upon a local tax base is a legitimate environmental factor that must be considered under NEPA.").

Concerned Scientists (UCS) (Docket No. NHTSA-2011-0056-0759). The letter from UCS included 605 unique comments that had been previously submitted to the group. Additionally, more than 10,000 largely identical letters were submitted by the National Wildlife Federation Action Fund to EPA on behalf of its supporters (Docket No. NHTSA-2011-0056-2067).

Several advocacy groups stated that higher CAFE standards can result in national security benefits, broad economic benefits, benefits to consumers (both in terms of savings and consumer choice), and competitive advantages for U.S. companies. Advocacy groups also mentioned the potential benefits of the proposal related to human health, climate change, air quality, and biological resource protection. Advocacy groups applauded NHTSA and EPA for their collaboration in setting one unified national standard. However, EDF warned that NHTSA's CAFE program must reflect the same certainty and durability as EPA's program under the CAA to ensure long-term benefits and provide manufacturers certainty for making capital investments. NHTSA recognizes the benefits of the proposed rule and, in an effort to promote regulatory certainty and maximize lead time for manufacturers, is working with EPA to continue the Joint National Program for MYs 2017–2025. *See* NHTSA's Preliminary RIA for more information regarding the benefits of the rule, including the projected economic benefits; *see* Chapters 4, 5, and 6 of this EIS for information regarding the projected environmental and health benefits of the proposal.

Groups such as CBD and NRDC supported the proposed approach of analyzing the action for the MY 2017–2025 period in a single EIS. However, CBD commented that the extended time period for this rulemaking and the emphasis on industry lead-times will result in standards that are too low. That group insisted that a mid-term review is necessary but only if it is limited to an analysis of technical advancement to identify whether further increased standards are appropriate. NRDC suggested that a second EIS at mid-term review is unnecessary, because it creates regulatory uncertainty and undermines future technological development. Because NHTSA's proposal covers the MY 2017–2025 period, and because the proposal is part of a joint NHTSA/EPA rulemaking for a coordinated National Program, this EIS addresses the potential environmental impacts of the proposed alternatives for the full MY 2017–2025 period together.[54] For the mid-term review, NHTSA will perform a de novo notice and comment rulemaking, taking into account all legal requirements and all relevant facts and scientific information known and available to the agency.

Advocacy groups also provided comments on the potential alternatives proposed for the EIS analysis. EDF cautioned that NHTSA must be transparent in selecting its preferred alternative and must include an explanation as to why this alternative represents the "maximum feasible" CAFE stringency, as required under EPCA. Sierra Club, Safe Climate Campaign, Environment America, and CBD stated that NHTSA's proposed range of alternatives should be based on a full analysis. A full explanation of NHTSA's considerations in developing the proposal, including the balancing of the four statutory factors the agency must consider when setting "maximum feasible" CAFE standards, is provided in the NPRM.

Regarding stringency, commenters, including NRDC, suggested excluding weak standards from the EIS analysis, asserting that these standards are unlawful because they represent only status quo improvements, not the maximum feasible improvement. Sierra Club, Safe Climate Campaign, and Environment America also stated that, as with domestic vehicles, NHTSA must adopt a backstop to prevent the attribute-based standards from being undermined. In general, advocacy groups expressed the need for the strongest possible standards, many of which

[54] *See* 40 CFR 1508.18(b)(3) (including as federal actions under NEPA ''[a]doption of programs, such as a group of concerted actions to implement a specific policy or plan; systematic and connected agency decisions allocating agency resources to implement a specific statutory program or executive directive.'').

specified 60 mpg by 2025 as an appropriate target. Groups such as the National Wildlife Federation Action Fund, Sierra Club, Safe Climate Campaign, Environment America, and UCS noted that current technology is more than sufficient to achieve this standard. Some commenters suggested that higher and more aggressive standards are realistic, including a 70, 75, or 100 mpg standard by 2025, a standard of 60 mpg sooner than 2025, or standards of 50 mpg by 2015, 60 by 2020, and 70 by 2025. Several groups also requested that NHTSA include a true technology-forcing alternative in its analysis, stating that the NHTSA 7 percent fuel economy increase should not be treated as a ceiling for the range of alternatives considered. CBD recommended taking into account not just available technologies, but all emerging technologies to select a technology-forcing range of alternatives. NHTSA continues to believe that the "maximum feasible" standards fall within the range of a 2 percent to 7 percent average annual increase for MYs 2017–2025. At this time, NHTSA has tentatively concluded that CAFE standards above 7 percent are not reasonable, because they do not sufficiently account for economic practicability and technological feasibility.

Sierra Club, Safe Climate Campaign, and Environment America suggested that the "no action" alternative should not assume action has not been taken to improve fuel economy and reduce GHGs; rather the "no action" alternative must include the cumulative effect of past federal and state standards. To better account for the cumulative effects of past actions, NHTSA has refined its methodology for direct and indirect impacts analysis and cumulative impacts analysis in this EIS.

UCS and supporters of the National Wildlife Federation Action Fund suggested that the agency include analysis of new alternatives, including vehicles fueled by various forms of alternative energies, higher hybrid penetration, better city planning, and enhanced rail, public, and alternative methods of transportation. NHTSA recognizes that alternative-fueled vehicles can significantly reduce fuel consumption; however, the agency does not mandate that manufacturers adopt specific technologies. Rather, manufacturers may choose from a suite of available technologies in meeting the standards. NHTSA anticipates that some manufacturers might respond to the new standards by increasing the proportion of hybrid and alternative-fueled vehicles in their fleets. At the same time, while NHTSA recognizes the benefits of transportation and city planning, as well as alternative modes of transportation, NHTSA's regulatory authority extends only to vehicles and vehicle equipment.

Advocacy groups commented on the comparison of alternatives in the upcoming EIS. EDF suggested that NHTSA "analyze each annual fuel economy increase within the range proposed, including 2%, 3%, 4%, 5%, 6%, and 7%." NHTSA continues to believe that providing an analysis of the upper and lower bounds of this range, in addition to the Preferred Alternative, provides sufficient information for decisionmakers and the public to assess the environmental impacts of this range of alternatives. Groups including Sierra Club, Safe Climate Campaign, and Environment America stated that NHTSA must be careful not to artificially minimize climate change impacts by analyzing them only as a proportion of global GHG emissions. Similarly, NRDC suggested that in calculating the effects of climate change, NHTSA needs to consider benefits in a global context. Other suggestions for comparing alternatives in the EIS included assessing regional U.S. impacts through regional models, estimating climate change impacts in conjunction with direct and indirect responses at both the global and local levels, and demonstrating the impact each alternative would have on avoiding a temperature increase of 2 degrees Celsius (3.6 degrees Fahrenheit). In general, commenters agreed that the EIS alternatives analysis must meaningfully quantify the different climate change impacts of the various alternatives to ensure informed decisionmaking. Specifically, EDF suggested that, when feasible, NHTSA must estimate quantitatively all health and environmental benefits of each alternative; otherwise, when monetization is not feasible, NHTSA must explain why and consider impacts qualitatively. NHTSA has endeavored to provide a full analysis, including quantitative analysis of health and environmental benefits of the alternatives. The agency has also endeavored to present meaningful context (e.g., considering the impacts of the alternatives in comparison to global and U.S. GHG emissions).

Advocacy groups also raised issues related to the economic and technological assumptions used in the EIS. Sierra Club, Safe Climate Campaign, and Environment America suggested that NHTSA include upstream emissions from electricity generation associated with electric vehicles. Those groups also suggested measuring electric vehicle performance using a national grid emissions factor for each model year combined with vehicle efficiency. CBD, supporters of the UCS, and NRDC stated that it is critical to consider upstream emissions from all vehicles, including electric and alternative-fuel vehicles, particularly because of electricity production from coal combustion and oil-burning power plants. NHTSA accounts for upstream emissions, including upstream emissions related to the production of electricity, in its environmental analysis in this EIS. Furthermore, in response to comments such as these, the agency has added a chapter to the EIS synthesizing the literature regarding life-cycle environmental impacts of certain vehicle materials and technologies. This chapter includes a discussion of upstream emissions resulting from electric vehicle use (*see* Chapter 6).

In general, advocacy groups agreed that accurate assumptions for upstream emissions, payback period, discount rate, fuel prices, energy security, and other qualitative and quantitative inputs in the Volpe model were important for presenting the true benefits of the National Program. Sierra Club, Safe Climate Campaign, and Environment America emphasized the importance that accurate oil prices have in reflecting the benefits of stronger fuel emissions standards. Those groups and others also noted that the current economic trends have boosted and will likely continue to boost fuel prices. Most of the advocacy groups and supporters stated that technological assumptions should account for existing technologies that can already achieve the strongest standards proposed. Sierra Club, Safe Climate Campaign, and Environment America suggested that NHTSA consider a full range of available fuel saving technologies, including down-weighting. The agency has carefully considered all assumptions and inputs, in addition to considering a broad range of available and developing technologies, in proposing CAFE standards and reasonable alternatives. These assumptions are set forth in the Interim Joint Technical Assessment Report, NPRM, and NHTSA's Preliminary RIA.

Advocacy groups also commented on the topic of specific environmental impacts of the program. Several groups expressed concern that the EIS would not account for all quantitative and qualitative benefits, thereby undermining the importance of the rule. EDF specifically requested that the EIS include an analysis of energy security benefits, social benefits, benefits from reduced criteria and hazardous air pollutants, and GHG leakage effects. Regarding air quality impacts specifically, Sierra Club, Safe Climate Campaign, and Environment America stated that the analysis should compare avoided air pollutant emissions that would result from reductions in oil refining due to decreases in overall oil demand under the different alternatives. Regarding general impacts to health, many advocacy groups supported stronger standards as a preventive measure – a way to reduce premature mortality, acute respiratory symptoms, and other medical conditions. NHTSA accounts for a wide range of relevant environmental benefits, including reductions in upstream emissions, throughout this EIS. In particular, *see* Section 4.1.2.6 for a discussion of upstream emissions in the context of air pollutant emissions.

Advocacy groups also emphasized the need for the EIS to contain the full range of climate impacts of the new standards. Sierra Club, Safe Climate Campaign, and Environment America specifically stated that the impacts from all GHGs, criteria air pollutants, and other toxic air emissions beyond carbon dioxide emissions must be evaluated. Advocacy groups emphasized that beyond just global temperature, precipitation, and sea-level changes, other indirect climate change impacts mentioned should include increases in the incidence and intensity of food-borne diseases and food and water contamination; reduced biodiversity from extinction, declining species populations, and ecosystem destruction; ocean warming and ocean acidification, which could threaten marine food resources by disrupting marine communities and increasing contaminants in fish and shellfish; increases in extreme weather such as heat waves and intense storms, which impact the health and safety of the human population, could increase power outages nationwide, and could disrupt other oil and coal infrastructure and transport; and impacts of oil spills from the level of drilling accompanying each standard. NHTSA appreciates these comments regarding the scope of environmental impacts the agency should analyze. The agency has included quantitative or qualitative discussions, when possible, of a wide range of potential environmental impacts in Chapters 4 through 7.

Other factors in the climate analysis that received attention in scoping comments include the social cost of carbon (SCC), tipping points, and extreme climate events. EDF and Sierra Club, Safe Climate Campaign, and Environment America stated that it is critical to perform an SCC analysis to ensure inclusion of the full range of potential costs climate change imposes on society. Similarly, CBD noted that SCC must be accounted for accurately. Additionally, NRDC suggested that when considering SCC, NHTSA should use Office of Management and Budget and EPA discount rates, use declining discount rates over time to account for risk aversion to uncertainty in interest rates, and place more weight on poor countries that bear more burden than wealthy countries. CBD also suggested NHTSA include an alternative that accounts for and avoids or minimizes the likelihood of reaching climate change tipping points. For information regarding SCC values used in this EIS, tipping points, and extreme climate events, *see* Chapter 5.

Advocacy groups called attention to the specific NEPA requirement that this EIS consider mitigation measures for environmental impacts from the new standards. In particular, Sierra Club, Safe Climate Campaign, and Environment America suggested that NHTSA consider measures that reduce vehicle miles traveled. NHTSA notes, however, that such mitigation measures are beyond the scope of the agency's jurisdiction.

1.5.1.3 Industry Organizations

NHTSA received letters from five industry groups: the Alliance of Automobile Manufacturers (Docket No. NHTSA-2011-0056-0033), Edison Electric Institute (Docket No. NHTSA-2011-0056-0762), the Aluminum Association, Inc. (Docket No. NHTSA-2011-0056-2064), Consulting Resources Corporation (Docket No. NHTSA-2011-0056-2063), and TIAX LLC (Docket No. NHTSA-2011-0056-2065).

The Alliance of Automobile Manufacturers stated that the ability to make accurate predictions and assumptions for the factors being considered in this EIS becomes more uncertain beginning in MY 2021. Accordingly, the Alliance suggested that the NHTSA and EPA proposed mid-term review of the proposed standards be completed in 2019 to allow time to adjust the standards in line with real-world conditions for MY 2021. The Alliance urged that, when selecting the preferred alternative, NHTSA carefully consider economic practicability without overemphasizing energy conservation and climate change considerations, because the latter two factors are likely to result in future benefits well below those estimated by the agency. *See* Section IV.F of the NPRM for a description of how NHTSA weighed the statutory factors in developing the proposal.

Further, the Alliance asked NHTSA to consider in this EIS, as it has in the past, that new vehicle prices resulting from higher standards will lead to longer vehicle retention, resulting in increased levels of GHGs and smog-forming pollutants. The Alliance also asked that NHTSA consider that VMT increases over time as per-mile costs for driving decrease. NHTSA considered a broad range of inputs in developing the proposed rule, including the rebound effect, as described in the NPRM.

Both the Alliance and Edison Electric Institute advised against requiring manufactures of plug-in hybrid electric vehicles, battery electric vehicles, and fuel-cell vehicles to account for upstream emissions from electricity generation. The Alliance stated that because electric and hybrid car manufacturers have no control over these emissions, they should not be held accountable for them under the proposed rule. Edison suggested that this EIS consider the environmental benefits that increased plug-in electric vehicle deployment will bring as a result of the new standards, particularly increased fuel efficiency, reduced dependence on petroleum, reduced GHG emissions and criteria pollutants from the transportation sector, and reduced upstream emissions of GHGs and criteria pollutants from the generation of electricity. Furthermore, Edison suggested that if NHTSA assesses upstream emissions of electric vehicles, it should make qualified comparisons and look at the increases and decreases of all emissions, including electricity generation. Edison suggested that if NHTSA addresses upstream emissions related to electricity generation, it should adopt a “full and fair” fuel-neutral analysis of electric vehicle deployment, comparing all vehicle types and fuels for both conventional and plug-in electric vehicles. Edison suggested that NHTSA reject EPA’s framework for assessing upstream emissions from electricity generation because it calculates a nationwide annual average electricity upstream GHG emissions rate that does not account for the significant regional difference in electricity generation, relies on outdated information, and does not consider the full impacts of conventional vehicles and fuels. Additionally, Edison suggested that if NHTSA chooses to include upstream or criteria pollutant emissions in this EIS, NHTSA consider upstream emissions along the supply chain of gasoline and diesel fuel that occur outside the United States. Chapters 2 and 4 discuss the agency’s approach to upstream emissions in calculating environmental impacts for this EIS. In addition, the agency has added a literature synthesis of the lifecycle impacts of vehicles and vehicle technologies, which includes a discussion of upstream emissions for electric vehicles (*see* Chapter 6).

In assessing air quality benefits from electric vehicles, Edison suggested that NHTSA consider that emissions from electric plants are better controlled than those from vehicles because electric plants must be in continuous compliance with emission requirements. Edison also emphasized the role of battery recycling and alternative uses, and requested that the EIS include robust assumptions about the likelihood of battery recycling and the secondary uses of batteries. NHTSA discusses these issues in the literature synthesis that appears in Chapter 6 of this EIS.

The Aluminum Association suggested that NHTSA consider all of the benefits of down-weighting, including the use of aluminum in vehicle design. In addition, regarding the life-cycle analysis of metals, the Aluminum Association advocated that NHTSA consider emissions related to mining, refining, and recycling. The commenter placed particular emphasis on the synergies created by mass reduction combined with advanced powertrain technologies, such as hybrids and electric vehicles. The literature synthesis of life-cycle impacts (Chapter 6 of this EIS) includes a discussion of various studies regarding materials replacement in the context of vehicle mass reduction.

Consulting Resources Corporation (CRC) proposed expanding the scope of the EIS to include the environmental impacts of ozone and other engine-exhaust pollutants, such as peroxyacetyl nitrate. CRC indicated that these substances affect the health of human communities and roadside vegetation because both substances have been proven deleterious to animal and vegetative health. CRC stated particular concern over the growing trend of blending gasoline with ethanol, which, they asserted, creates a more volatile fuel that increases emissions by up to 5 percent compared to pure gasoline. NHTSA includes an analysis of the projected impacts of the proposal in terms of relevant criteria pollutants and hazardous air pollutants in Chapter 4 of this EIS.

TIAX generally agreed with NHTSA's planned approach to quantifying the energy, air quality, and climate change impacts of the proposal, but recommended that at least one of the alternatives considered in the EIS include a large percentage of zero-emissions vehicles. TIAX indicated that this alternative should assume a larger percentage of these vehicles to be located in California. NHTSA's approach for forecasting sales of advanced vehicles is discussed more thoroughly in the NPRM and NHTSA's Preliminary RIA.

1.5.1.4 Individuals

Four individuals provided scoping comments: Jean Public (Docket No. NHTSA-2011-0056-0002), Stephen Shoap (Docket No. NHTSA-2011-0056-0003), Christopher Lish (Docket No. NHTSA-2011-0056-1627), and Joyce Dillard (Docket No. NHTSA-2011-0056-2043).

Jean Public stated that the agency should not consider the No Action Alternative. NHTSA notes that even though the recent EISA amendments to EPCA do not permit NHTSA to take no action on fuel economy, NEPA requires consideration of a no action alternative in the agency's analysis. For the purposes of this EIS, the NHTSA No Action Alternative represents a baseline from which to compare the different environmental effects of the action alternatives.

Ms. Public and Mr. Lish encouraged stronger fuel economy standards than those proposed. Ms. Public specifically suggested that NHTSA raise fuel economy standards to 100 mpg. In developing the proposed standards, NHTSA was bound by the consideration of four statutory factors. Having carefully weighed these factors as described in Section IV.F of the NPRM, NHTSA believes that such a high level of stringency is outside the range of "maximum feasible" increases in fuel economy.

Stephen Shoap recommended that NHTSA consider a new bumper technology as a means of making cars safer and more energy efficient. For more information about the technologies the agency has considered in developing the proposed standards, *see* the NPRM and NHTSA's Preliminary RIA.

Joyce Dillard inquired whether electric vehicles and their power supplies were being considered in the analysis. Additionally, Ms. Dillard asked about the cost of infrastructure related to this rulemaking. Electric vehicles are considered in Chapter 6 of this EIS. An infrastructure assessment appears in the Interim Joint Technical Assessment Report.

1.6 Next Steps in the National Environmental Policy Act and Joint Rulemaking Process

This Draft EIS is being issued for public review and comment concurrently with the NPRM to establish passenger car and light truck CAFE and GHG emission standards issued jointly by NHTSA and EPA. Individuals may submit their written comments on the Draft EIS, identified by docket number NHTSA-2011-0056, by any of the following methods:

- Federal eRulemaking Portal: Go to http://www.regulations.gov. Follow the instructions for submitting comments on the electronic docket site by clicking on "Help" or "FAQ." The Docket Number for this EIS is "NHTSA-2011-0056."
- Mail: Docket Management Facility, M-30, U.S. Department of Transportation, 1200 New Jersey Avenue SE, West Building, Ground Floor, Room W12-140, Washington, D.C. 20590.
- Hand Delivery: 1200 New Jersey Avenue SE, West Building Ground Floor, Room W12-140, between 9 a.m. and 5 p.m. eastern time, Monday through Friday, except federal holidays.
- Fax: 202-493-2251.

NHTSA expects to release the Final EIS in mid 2012. The Final EIS will address comments received on the Draft EIS. No sooner than 30 days after EPA announces the availability of the Final EIS in the *Federal Register*, NHTSA will publish a final rule and Record of Decision. The Record of Decision will state and explain NHTSA's decision.

CHAPTER 2 PROPOSED ACTION AND ALTERNATIVES AND ANALYSIS METHODOLOGIES

2.1 Introduction

NEPA requires an agency to evaluate the environmental impacts of its proposed action and alternatives to that action.[1] An agency must rigorously explore and objectively evaluate all reasonable alternatives, including the alternative of taking no action. For alternatives an agency eliminates from detailed study, the agency must "briefly discuss the reasons for their having been eliminated."[2] The purpose of and need for the agency's action provides the foundation for determining the range of reasonable alternatives to be considered in its NEPA analysis.[3]

The remainder of this chapter describes the Proposed Action and alternatives examined in this EIS; explains the methodologies and assumptions applied in the analysis of environmental impacts; and summarizes environmental impacts reported in subsequent EIS chapters, as follows:

- Section 2.2, Proposed Action and Alternatives
- Section 2.3, Standards-setting and EIS Methodologies and Assumptions
- Section 2.4, Resource Areas Affected and Types of Emissions
- Section 2.5, Direct and Indirect versus Cumulative Impacts
- Section 2.6, Comparison of Alternatives

2.2 Proposed Action and Alternatives

For this action, NHTSA's proposal is to set fuel economy standards for MY 2017–2025 passenger cars and light trucks in accordance with EPCA, as amended by EISA. In developing the proposed standards and alternatives, NHTSA considered the four EPCA factors that guide the agency's determination of "maximum feasible" standards: technological feasibility; economic practicability; the effect of other motor vehicle standards of the government on fuel economy; and the need of the United States to conserve energy.[4] In addition, NHTSA considered relevant environmental and safety factors.[5] During the process of developing standards, NHTSA has consulted with EPA and the U.S. Department of Energy (DOE) regarding a variety of matters, as required by EPCA.[6]

NHTSA has selected a reasonable range of alternatives to evaluate the potential environmental impacts of the proposed CAFE standards and alternatives under NEPA. Consistent with CEQ NEPA implementing regulations, this EIS compares the proposal and a reasonable range of

[1] 42 U.S.C. § 4332(2)(C).
[2] 40 CFR §§ 1502.14(a), (d).
[3] 40 CFR § 1502.13. *See Vermont Yankee Nuclear Power Corp. v. Natural Res. Def. Council*, 435 U.S. 519, 551 (1978); *City of Alexandria v. Slater*, 198 F.3d 862, 867-69 (D.C. Cir. 1999), *cert. denied sub nom.*, 531 U.S. 820 (2000).
[4] 49 U.S.C. § 32902(f).
[5] As noted in Chapter 1, NHTSA interprets the statutory factors as including environmental issues and permitting the consideration of other relevant societal issues, such as safety. *See*, e.g., *Competitive Enterprise Inst. v. NHTSA*, 956 F.2d 321, 322 (D.C. Cir. 1992) (citing *Competitive Enterprise Inst. v. NHTSA*, 901 F.2d 107, 120 n.11 (D.C. Cir. 1990)); and Average Fuel Economy Standards, Passenger Cars and Light Trucks; Model Years 2011–2015, 73 FR 24352 (May 2, 2008).
[6] 49 U.S.C. § 32902(i).

alternatives to the No Action Alternative (Alternative 1), which assumes that NHTSA and EPA would not issue a rule regarding CAFE or greenhouse gas (GHG) emission standards.[7]

Under EPCA, as amended by EISA, NHTSA is required to set separate average fuel economy standards for passenger cars and light trucks. Because NHTSA intends to set standards both for cars and for trucks, and because the environmental impacts of this proposal require consideration of the impacts of the standards for both vehicle classes, the main analyses presented in this EIS reflect the combined environmental impacts associated with the proposed standards for passenger cars and light trucks. In addition, Appendix A shows separate results for passenger cars and light trucks under each alternative.

2.2.1 Alternative 1: No Action

The No Action Alternative assumes that NHTSA would not issue a rule regarding CAFE standards for MY 2017–2025 passenger cars and light trucks; rather, consistent with previous EISs, the agency assumes that NHTSA's MY 2016 fuel economy standards and EPA's MY 2016 GHG standards would continue indefinitely. This alternative provides an analytical baseline against which to compare the environmental impacts of the other regulatory alternatives.[8] NEPA expressly requires agencies to consider a ''no action'' alternative in their NEPA analyses and to compare the effects of not taking action with the effects of action alternatives to demonstrate the environmental effects of the action alternatives. The No Action Alternative assumes that average fuel economy levels and GHG emissions performance in the absence of the agencies' action would equal what manufacturers would achieve without regulation. The No Action Alternative would yield no additional environmental improvement other than what might occur from market forces. The environmental impacts of other alternatives are calculated in relation to the baseline of the No Action Alternative.

If NHTSA were to not adopt new fuel economy standards, it is possible that manufacturers would attain an average fleetwide fuel economy no better than that required under the agencies' existing MY 2016 standards. An assumption that fleetwide fuel economy would generally remain unchanged in the absence of additional action under the National Program, described more fully in the Notice of Proposed Rulemaking (NPRM), is based on projections of relatively stable fuel prices, certain historical evidence of manufacturer CAFE compliance, and market observations wherein consumers appear not to purchase products that are in their economic self-interest (the "Energy Paradox").

However, it is important to note that in the context of vehicle fuel economy, selecting an appropriate baseline against which to compare this proposal and the alternatives is complex and challenging. As we recently stated regarding the agencies' new standards for heavy-duty (HD) vehicles, it is not possible to know with certainty the future fleetwide fuel efficiency and GHG emissions performance of a vehicle fleet in the absence of more stringent standards, which depends on many factors beyond the agency's control.

[7] 40 CFR § 1502.14(d).

[8] *See* 40 CFR §§ 1502.2(e), 1502.14(d). CEQ has explained that "[T]he regulations require the analysis of the no action alternative even if the agency is under a court order or legislative command to act. This analysis provides a benchmark, enabling decision makers to compare the magnitude of environmental effects of the action alternatives. [*See* 40 CFR § 1502.14(c).] * * * Inclusion of such an analysis in the EIS is necessary to inform Congress, the public, and the President as intended by NEPA. [*See* 40 CFR § 1500.1(a).]" Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations, 46 FR 18026 (Mar. 23, 1981).

NHTSA understands that market forces can independently result in changes to the future light-duty vehicle fleet even in the absence of the proposed rule, and that, to the extent they can be estimated, those changes should be incorporated into the baseline. In response to the MY 2014–2018 HD Draft EIS, NHTSA received several comments comparing the action alternatives to the HD vehicle annual energy consumption forecast produced by the U.S. Energy Information Administration (EIA) and describing that forecast, known as the Annual Energy Outlook (AEO), as "business as usual." In response to these comments, in the MY 2014–2018 HD Final EIS, the agency added a "Market Forecast Analysis" comparing the environmental impacts of the action alternatives to those of a baseline derived from the AEO forecast available at the time the EIS modeling was performed. That baseline assumed that market forces would independently result in increases in fuel efficiency in the future HD fleet even in the absence of the proposed rule.

NHTSA believes that similar considerations are appropriate and relevant to this analysis. From a market-driven perspective, there is considerable evidence that many customers now care more about fuel economy than in past decades due to, among other things, uncertainty over future fuel prices and growing concern for the energy security and environmental impacts of petroleum usage. A number of manufacturers have announced plans to introduce technology well beyond that required by the MY 2016 standards, and some historical evidence indicates that manufacturers might over-comply with standards under certain economic and regulatory conditions. Although fuel price projections reported in AEO appear relatively stable, there is inherent uncertainty in such projections and actual fuel prices could fluctuate, perhaps significantly, from what AEO forecasts. As a result of these considerations and comments received during the scoping process, the agency believes it is appropriate to compare action alternatives to a baseline that accounts for market forces and technology advances that would result in fuel economy gains even in the absence of regulatory action.

Therefore, in recognition of the uncertainty inherent in forecasting the fuel economy of the future vehicle fleet in the absence of the agencies' action, this EIS provides two analyses regarding the No Action Alternative and the corresponding impacts of action alternatives. Analysis A reflects a No Action Alternative that assumes that, in the absence of the Proposed Action, the baseline fleet in MYs 2017–2025 and beyond would attain an average fleetwide fuel economy no higher than that required under the agencies' MY 2016 standards established by final rule in April 2010. Table 2.2.1-2-A shows the estimated fleetwide fuel economy NHTSA forecasts manufacturers would achieve under the No Action Alternative in Analysis A.

Table 2.2.1-2-A. Analysis A Estimated Achieved U.S. Passenger Car and Light Truck Fleetwide Fuel Economy (mpg) by Model Year under the No Action Alternative

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger cars	37.8	38.3	38.6	38.9	39.0	39.1	39.1	39.2	39.2
Light trucks	29.2	29.5	29.7	29.8	29.9	30.0	30.0	30.1	30.1
Combined cars and trucks	33.4	33.8	34.1	34.4	34.5	34.6	34.7	34.8	34.9

Analysis B reflects a No Action Alternative that assumes that, in the absence of the agencies' action, the average fleetwide fuel economy level of light-duty vehicles would continue to increase beyond the level necessary to meet the MY 2016 standards.[9] NHTSA forecast this

[9] The No Action Alternative used in Analysis B is referred to as the "market-driven baseline" in NHTSA's Preliminary RIA and as "voluntary overcompliance" in the NPRM.

fleet using the "voluntary over-compliance" simulation capability of the Volpe model, described below and in Section IV.C.4.c of the NPRM. For this simulation, the agency used all of the same inputs as for Analysis A, but applied a payback period of 1 year for purposes of calculating the value of future fuel savings when simulating whether a manufacturer would apply additional technology to an already CAFE-compliant fleet.[10] For technologies applied to a manufacturer's fleet that has not yet achieved compliance with CAFE standards, the agency continued to apply a 5-year payback period. Further discussion of this methodology is available in Section IV.G of the NPRM. Table 2.2.1-2-B shows the estimated fleetwide fuel economy NHTSA forecasts manufacturers would achieve under the No Action Alternative in Analysis B.

Table 2.2.1-2-B. Analysis B Estimated Achieved U.S. Passenger Car and Light Truck Fleetwide Fuel Economy (mpg) by Model Year under the No Action Alternative

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger cars	37.7	38.3	38.6	38.8	38.9	39.0	39.1	39.2	39.3
Light trucks	29.1	29.7	29.9	30.1	30.2	30.3	30.4	30.5	30.8
Combined cars and trucks	33.3	33.9	34.2	34.5	34.6	34.7	34.9	35.1	35.3

Tables in this section and Section 2.2.2 present estimated required and/or achieved fleetwide fuel economy levels under NHTSA's proposed standards. The estimated average *required* fuel economy levels for passenger cars and light trucks under the proposed standards include the use of air conditioner efficiency improvements, as discussed in Chapter 1. These levels do not reflect a number of proposed flexibilities and credits that manufacturers could use for compliance that NHTSA cannot consider in establishing standards based on EPCA/EISA constraints. The flexibilities and credits NHTSA cannot consider include the ability of manufacturers to pay civil penalties rather than achieving required CAFE levels, the ability to use flexible fuel vehicle credits, the ability to count electric vehicles (EVs) for compliance, the operation of plug-in hybrid electric vehicles on electricity for compliance before MY 2020, and the ability to transfer and carry forward credits. Because this EIS evaluates real-world environmental impacts, the estimated average *achieved* fuel economy levels include the use of air conditioner efficiency improvements in addition to the flexibilities and credits listed above. In addition, this EIS uses a weighted average of flexible fuel vehicles' fuel economy levels when operating on gasoline and on E85 (a blend of 15 percent gasoline and 85 percent ethanol, by volume). In particular, the EIS assumes that flexible fuel vehicles operate on gasoline 85 percent of the time and on E85 the remaining 15 percent of the time.

2.2.2 Action Alternatives

NHTSA has analyzed a range of action alternatives with stringencies that increase annually, on average, 2 percent to 7 percent from the MY 2016 standards for cars and for trucks. As NHTSA stated in the Notice of Intent to issue an EIS, the agency believes that, based on the different ways the agency could weigh EPCA's four statutory factors, the "maximum feasible" level of CAFE stringency falls within this range.[11]

[10] In other words, NHTSA assumes that manufacturers will act as if buyers value the resulting savings in fuel costs associated with additional fuel economy technology only during their first year of ownership. If a consumer will not recover the full cost of the additional technology within the first year of vehicle ownership, NHTSA assumes the manufacturer will not incorporate that technology.

[11] For a full discussion of the agency's balancing of the statutory factors related to "maximum feasible" standards, consult the Notice of Proposed Rulemaking.

Throughout this EIS, estimated impacts are shown for three action alternatives that illustrate this range of average annual percentage increases: a 2 percent per year average increase for both passenger cars and light trucks (Alternative 2); a Preferred Alternative with annual percentage increases for passenger cars and for light trucks that, on average, fall between the 2 percent and 7 percent per year increase (Alternative 3); and a 7 percent per year increase for both passenger cars and light trucks (Alternative 4).

Alternatives 2 and 4 are intended to provide the upper and lower bounds of a reasonable range of alternatives within which the agency believes the maximum feasible standards fall. This range encompasses a spectrum of possible standards the agency could select, based on the different ways NHTSA could weigh EPCA's four statutory factors. By providing environmental analyses of these points and the Preferred Alternative, the decisionmaker and the public can determine the environmental impacts of points that fall between Alternatives 2 and 4. The action alternatives evaluated in this EIS therefore provide decisionmakers with the ability to select from a wide variety of other potential alternatives with stringencies that increase annually at average percentage rates between 2 and 7 percent. This includes, for example, alternatives with stringencies that increase at different rates for passenger cars and for light trucks and stringencies that increase by different rates in different years.

As discussed above, there is considerable uncertainty about whether and to what degree fleetwide fuel economy changes in the absence of agency action. After the rulemaking period, in the absence of further action to regulate CAFE or GHG emissions, there should be similar considerations regarding manufacturers' incentive to increase fuel economy, as discussed above. For example, assuming that market forces would lead to an increase in fuel economy in the absence of the rule, it is reasonable to also assume continued growth in fuel economy after the rulemaking period. Therefore, for Analysis A, the agency has assumed that fleetwide fuel economy after MY 2025 will never exceed the level of the MY 2025 standards.

In contrast, for Analysis B, the agency has assumed that fleetwide fuel economy will continue to increase after MY 2025 beyond the levels necessary to meet the MY 2025 standards. Specifically, the agency assumes that the fuel economy achieved by new passenger cars and light trucks will increase at rates of 0.2 percent and 0.4 percent annually after MY 2025. These rates of increase were developed by examining historical changes in the fuel economy of new passenger cars and light trucks during periods when CAFE standards remained fixed, and therefore did not require manufacturers to offer vehicles with higher fuel economy than in the immediately preceding model years. While the actual fuel economy of new vehicles produced during such years was undoubtedly affected by many factors other than CAFE standards, the agency views these figures as reasonable estimates of the likely trend in fuel economy in model years following 2025.

Therefore, Analysis A and Analysis B differ only in relation to fuel economy gains in the baseline and after 2025. The MY 2017–2025 average annual percentage increases in CAFE requirements for each action alternative (described in Sections 2.2.2.1 through 2.2.2.3) are essentially the same for both analyses.[12]

[12] Differences in modeling assumptions necessary to provide these two analyses resulted in slight differences in achieved fuel economy values during the regulatory period, which are not expected to have significant environmental impacts over the long term.

2.2.2.1 Alternative 2: 2 Percent per Year Increase in Fuel Economy

Alternative 2 would require a 2 percent average annual fleetwide increase in mpg for passenger cars and light trucks for MYs 2017–2025. As noted above, Alternative 2 represents the lower bound of the range of annual stringency increases that NHTSA believes includes the maximum feasible stringency. Table 2.2.2-1 lists the estimated required and achieved fleetwide fuel economy NHTSA forecasts under Alternative 2.

Table 2.2.2-1. Estimated U.S. Passenger Car and Light Truck Fleetwide Fuel Economy (mpg) by Model Year under Alternative 2

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Required									
Passenger cars	39.4	40.2	41.1	41.9	42.8	43.7	44.6	45.5	46.5
Light trucks	30.1	30.8	31.6	32.2	32.8	33.6	34.3	35.1	35.8
Combined cars and trucks	35.4	36.2	37.1	37.9	38.7	39.6	40.4	41.4	42.3
Achieved									
Passenger cars	38.5	39.7	41.0	42.1	42.9	43.6	44.0	44.8	45.3
Light trucks	30.0	31.0	32.3	33.2	34.1	34.4	35.0	35.5	35.8
Combined cars and trucks	34.1	35.3	36.7	37.7	38.6	39.2	39.7	40.4	40.9

2.2.2.2 Alternative 3: Preferred Alternative

Alternative 3 represents the agency's Preferred Alternative, under which manufacturers would be required to meet an estimated average fleetwide fuel economy level of 40.9 mpg in MY 2021. For passenger cars, the annual increase in the stringency between MYs 2017 and 2021 averages 4.1 percent. In recognition of manufacturers' unique challenges in improving the fuel economy and GHG emissions of full-size pickup trucks as we transition from the MY 2016 standards to MY 2017 and later, while preserving the utility (e.g., towing and payload capabilities) of those vehicles, NHTSA is also proposing a slower annual rate of improvement for light trucks in the first phase of the program. For light trucks, the proposed annual increase in the stringency in MYs 2017 through 2021 averages 2.9 percent per year.

The second phase of the CAFE program runs from MYs 2022–2025 and represents conditional[13] proposed standards that are projected to require, on an average industry fleetwide basis, 49.6 mpg in model year 2025. For passenger cars, the annual increase in the stringency between MYs 2022 and 2025 is expected to average 4.3 percent, and for light trucks, the annual increase during those model years is expected to average 4.7 percent.

Table 2.2.2-2 lists the estimated required and achieved fleetwide fuel economy NHTSA forecasts under the Preferred Alternative.

[13] By "conditional," NHTSA means that the proposed standards for MYs 2022–2025 represent the agency's current best estimate of what levels of stringency would be maximum feasible in those model years, but in order for the standards for those model years to be legally binding, a subsequent rulemaking must be undertaken by the agency at a later time. *See* Section IV of the NPRM for more information.

Table 2.2.2-2. Estimated U.S. Passenger Car and Light Truck Fleetwide Fuel Economy (mpg) by Model Year under the Preferred Alternative

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Required									
Passenger cars	40.0	41.4	43.0	44.7	46.6	48.8	51.1	53.5	56.0
Light trucks	29.4	30.0	30.6	31.2	33.3	34.9	36.7	38.5	40.3
Combined cars and trucks	35.3	36.4	37.5	38.8	40.9	42.9	45.0	47.3	49.6
Achieved									
Passenger cars	39.2	40.9	43.1	44.7	46.2	47.3	48.4	50.1	52.4
Light trucks	29.8	31.0	32.7	34.1	35.8	36.6	37.9	39.2	40.3
Combined cars and trucks	34.3	35.8	37.8	39.4	41.0	42.0	43.3	44.9	46.7

2.2.2.3 Alternative 4: 7 Percent per Year Increase in Fuel Economy

Alternative 4 would require a 7 percent average annual fleetwide increase in mpg for both passenger cars and light trucks for MYs 2017–2025. As noted above, Alternative 4 represents the upper bound of the range of annual stringency increases that NHTSA believes includes the maximum feasible stringency. Table 2.2.2-3 shows the estimated required and achieved fleetwide fuel economy NHTSA forecasts under Alternative 4.

Table 2.2.2-3. Estimated U.S. Passenger Car and Light Truck Fleetwide Fuel Economy (mpg) by Model Year under Alternative 4

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Required									
Passenger cars	41.6	44.8	48.2	51.9	56.0	60.4	65.1	70.2	75.7
Light trucks	31.6	34.2	37.1	39.8	43.0	46.4	50.1	54.2	58.4
Combined cars and trucks	37.2	40.3	43.5	46.9	50.6	54.6	59.0	63.8	69.0
Achieved									
Passenger cars	41.3	43.8	46.5	49.3	50.7	52.6	55.6	59.8	63.3
Light trucks	32.2	34.3	36.8	39.2	40.5	42.1	43.8	46.2	47.3
Combined cars and trucks	36.6	39.0	41.7	44.3	45.8	47.5	49.9	53.3	55.6

2.2.3 EPA Greenhouse Gas Emission Standards

In conjunction with NHTSA's proposal, EPA has proposed GHG emissions standards under Section 202(a) of the Clean Air Act (CAA). EPA's proposed standards begin with MY 2017, increase in stringency through MY 2025, and would require light-duty vehicles to meet an estimated combined average emissions level of 163 grams per mile of carbon dioxide (CO_2) in MY 2025. The National Program represents a harmonized approach that will allow industry to build a single national fleet that will satisfy both the GHG requirements under the CAA and CAFE requirements under EPCA/EISA. However, given differences in their respective statutory authorities, the agencies' proposed standards include some important differences. *See* Section 1.3.2.1 for a discussion of these differences.

Table 2.2.3-1 provides EPA's estimates of its projected overall fleetwide CO_2 emissions compliance targets under the proposed standards.

Table 2.2.3-1. Projected U.S. Passenger Car and Light Truck Fleetwide Emissions Compliance Levels under the Proposed CO_2 Standards (grams/mile)

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger cars	213	202	192	182	173	165	158	151	144
Light trucks	295	285	277	270	250	237	225	214	203
Combined cars and trucks	243	232	223	213	200	190	181	172	163

EPA anticipates that manufacturers will take advantage of program flexibilities. Table 2.2.3-2 shows EPA's projection of the achieved emission levels of the fleet for MYs 2017–2025. The grams per mile values in Table 2.2.3-2 are CO_2-equivalent values because they include the projected use of air conditioning credits by manufacturers.

Table 2.2.3-2. Projected U.S. Passenger Car and Light Truck Fleetwide Achieved CO_2-equivalent Emissions Levels under the Proposed CO_2 Standards (grams/mile)

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger cars	215	205	194	184	174	165	158	151	144
Light trucks	295	285	278	271	251	238	226	214	204
Combined cars and trucks	245	234	224	214	201	190	181	172	164

2.2.4 Alternatives Considered but not Analyzed in Detail

In response to the agency's Notice of Intent, some commenters indicated that a 7 percent per year average annual increase in fuel economy standards was not a proper upper bound without the agency performing a full analysis. The agency has rigorously analyzed the various alternatives in the NPRM and continues to believe that the maximum feasible level of stringency on average falls between 2 percent per year and 7 percent per year for passenger cars and for light trucks. The agency has not analyzed an alternative in excess of a 7 percent per year increase for passenger cars and for light trucks because NHTSA believes that such an alternative would fall outside the range of where the maximum feasible level could fall, after a careful balancing of the four statutory factors discussed above. In particular, such a high level of stringency would place too little weight on economic practicability and technological feasibility.

In addition, one commenter indicated that NHTSA should include as an alternative the "maximum technologically feasible" levels of stringency. The agency does not believe this is a reasonable alternative in light of the four statutory factors. In particular, because technological feasibility is only one of four factors, such an alternative would essentially ignore the three other factors that the agency is required to consider when setting CAFE standards. Thus, NHTSA has not analyzed this alternative.

2.3 Standards-setting and EIS Methodologies and Assumptions

Each of the specific alternatives examined represents, in part, a different way in which NHTSA could conceivably balance conflicting policies and considerations in setting the standards. For example, the most stringent alternative, which increases both car and truck mpg standards on average by 7 percent per year and reflects the upper bound of where the agency believes the maximum feasible stringency falls, weighs energy conservation and climate change considerations more heavily and economic practicability and technological feasibility less heavily. In contrast, the least stringent alternative, which increases both car and truck mpg standards on average by 2 percent per year and reflects the lower bound of where the agency believes the maximum feasible stringency falls, places more weight on economic practicability.

After working with EPA in thoroughly reviewing the effectiveness and costs of technologies, as well as market forecasts and economic assumptions, NHTSA used a model to assess the technologies that manufacturers could apply to comply with each alternative. Section 2.3.1 describes this model and its inputs and provides an overview of the analytical pieces and tools used in the analysis of alternatives.

2.3.1 Volpe Model

Since 2002, as part of its CAFE analyses, NHTSA has employed a modeling system developed specifically to help the agency apply technologies to thousands of vehicles and develop estimates of the costs and benefits of potential CAFE standards. The CAFE Compliance and Effects Modeling System developed by the Volpe National Transportation Systems Center, and commonly referred to as “the Volpe model,” enables NHTSA to efficiently, systematically, and reproducibly evaluate many regulatory options. Generally, the model assumes that manufacturers apply the most cost-effective technologies first, and as more stringent fuel economy standards are evaluated, the model recognizes that manufacturers must apply less cost-effective technologies. The model then compares the discounted present value of costs and benefits associated with any specific potential CAFE standard. The Volpe model calculates average changes in vehicle costs (corresponding to total technology outlays and, where applicable, civil penalties). It does not predict manufacturers’ decisions regarding the pricing or production of specific vehicle models, nor does it currently estimate consumer behavioral responses, such as buying fewer vehicles or buying different types of vehicles.

The Volpe model produces various outputs, including estimates of year-by-year fuel consumption by U.S. passenger car and light truck fleets. For this EIS, NHTSA used the model to estimate annual fuel consumption and fuel savings for each calendar year from 2017, when the proposed standards considered in this EIS would first take effect, through 2060, when almost all passenger cars and light trucks in use would have met CAFE standards at least as stringent as those established for MY 2025.[14]

2.3.2 Volpe Model Inputs

The Volpe model requires estimates for the following types of inputs: (1) a forecast of the future vehicle market, (2) availability, applicability, and incremental effectiveness and cost of fuel-saving technologies, (3) vehicle survival and mileage accumulation patterns, (4) future fuel

[14] This assumes that if NHTSA does not establish more stringent CAFE standards for model years after MY 2025, the standards established for MY 2025 as part of the current rulemaking would be extended to apply to subsequent model years.

prices, (5) the rebound effect (the increase in vehicle use that results from improved fuel economy), (6) the "social cost of carbon" and other economic factors, (7) fuel characteristics and vehicular emissions rates, and (8) coefficients defining the shape and level of CAFE footprint-based curves, which use vehicle footprint (a vehicle's wheelbase multiplied by the vehicle's average track width) to determine the required fuel economy level or ''target.'' The model is a tool NHTSA uses for analysis; it makes no a priori assumptions regarding inputs such as fuel prices and available technologies and does not dictate the stringency or form of the CAFE standards to be examined. NHTSA makes those selections based on the best currently-available information and data.

Using NHTSA-selected inputs, the agency projects a set of technologies each manufacturer could apply to each of its vehicle models to comply with the various levels of potential CAFE standards to be examined for each fleet, for each model year. The model then estimates the costs associated with this additional technology utilization and accompanying changes in travel demand, fuel consumption, fuel outlays, emissions, and economic externalities related to petroleum consumption and other factors.

For additional information on the Volpe model and its inputs, *see* the NPRM and the Draft Joint Technical Support Document (TSD) and NHTSA's Preliminary Regulatory Impact Analysis (RIA). Model documentation, publicly available in the rulemaking docket and on NHTSA's website, explains how the model is installed, how the model inputs and outputs are structured, and how the model is used.

NHTSA considers the results of analyses using the Volpe model and external analyses, including assessments of GHGs and air pollution emissions, and technologies that might be available over the longer term. NHTSA also considers whether the standards could expedite the introduction of new technologies to the market, and the extent to which changes in vehicle costs and fuel economy might affect vehicle production and sales. Using all of this information, NHTSA considers the governing statutory factors, along with environmental issues and other relevant societal issues, such as safety, and promulgates the maximum feasible standards based on its best judgment on how to balance these factors.

2.3.2.1 Vehicle Market Forecast

To determine what levels of stringency are feasible in future model years, NHTSA and EPA must project what vehicles and technologies will exist in those model years and then evaluate what technologies can feasibly be applied to those vehicles to raise their fuel economy and lower their CO_2 emissions. The agencies therefore establish a baseline vehicle fleet representing those vehicles, based on the best available information and a reasonable balancing of various policy concerns, against which they can analyze potential future levels of stringency and their costs and benefits. For this EIS, NHTSA uses an adjusted 2008 baseline vehicle fleet based on CAFE certification data from EPA, updated with information from the EIA AEO for 2011, and information purchased from CSM-Worldwide. More information about the vehicle market forecast is available in Section II.B of the NPRM and Chapter 1 of the Draft Joint TSD.

2.3.2.2 Technology Assumptions

The analysis of costs and benefits employed in the Volpe model reflects NHTSA's assessment of a broad range of technologies that can be applied to passenger cars and light trucks. The technologies considered by the model encompass five broad categories of engine, transmission, vehicle, electrification/accessory, and hybrid technologies. More information about the technology assumptions can be found in Chapter 3 of the Draft Joint TSD and in Chapter V of NHTSA's Preliminary RIA.

2.3.2.3 Economic Assumptions

NHTSA's analysis of the energy savings, changes in emissions, and environmental impacts likely to result from Proposed Action and alternative standards relies on a range of forecasts, economic assumptions, and estimates of parameters used by the Volpe model. These economic values play a significant role in determining the reductions in fuel consumption, changes in emissions of criteria and toxic air pollutants and GHGs, reductions in U.S. petroleum imports, and resulting economic benefits of alternative standards. The forecasts, assumptions, and parameters used in the Volpe model include the following:

- Forecasts of sales of passenger cars and light trucks for MYs 2017–2025
- Assumptions about the fraction of these vehicles that remain in service at different ages, how rapidly average annual use of passenger cars and light trucks grows over time, and how passenger car and light truck use declines with their increasing age
- Forecasts of fuel prices over the expected lifetimes of MY 2017–2025 passenger cars and light trucks
- Forecasts of expected future growth in total passenger car and light truck use, including vehicles of all model years comprising the U.S. vehicle fleet
- The size of the gap between test and actual on-road fuel economy
- The magnitude of the fuel economy rebound effect, or the increase in vehicle use that results from improved fuel economy
- Economic costs associated with U.S. consumption and imports of petroleum and refined petroleum products, over and above their market prices
- Changes in emissions of criteria and toxic air pollutants and GHGs that result from saving each gallon of fuel and from each added mile of driving
- The economic values of reductions in emissions of criteria and toxic air pollutants and GHGs
- The value of increased driving range and less frequent refueling that results from increases in fuel economy
- The costs of increased congestion, traffic accidents, and noise caused by added passenger car and light truck use
- The discount rate applied to future benefits

The impacts of the alternatives evaluated in this EIS reflect a specific combination of economic inputs in the Volpe model. Detailed descriptions of the sources of forecast information, the rationale underlying each economic assumption, and the agency's choices of specific parameter values are included in Chapter 4 of the Draft Joint TSD and also in NHTSA's Preliminary RIA. NHTSA also analyzed the sensitivity of its estimates to plausible variations in the values of many of these variables. The specific values of these variables used in the NHTSA sensitivity analysis and their effects on estimates of fuel consumption and GHG emissions will be reported and discussed in NHTSA's Preliminary RIA.

2.3.2.4 The Rebound Effect

By reducing the cost of fuel consumed per mile driven, requiring increased fuel economy could create an incentive for additional vehicle use. Any resulting increase in vehicle use will offset part of the fuel savings that would otherwise be expected to result from higher fuel economy, a phenomenon known as the "rebound effect." The total amount of passenger car and light truck vehicle miles traveled (VMT) would increase slightly due to the rebound effect, and tailpipe emissions of pollutants strictly related to vehicle use would increase in proportion to the increased VMT. In this EIS, the estimated rebound effect for light-duty vehicles is 10 percent. These VMT impacts are reflected in the estimates of emissions under each of the alternatives evaluated (*see* Section 2.4.1 for more detail).

2.3.2.5 Vehicle Survival Rates

Passenger cars and light trucks typically remain in use for many years, so the changes in fuel use, emissions, and other environmental impacts due to NHTSA's Proposed Action will also continue for many years. However, the contribution to these impacts by vehicles produced during a particular model year declines over time as those vehicles are gradually retired from service, while those that remain in use are driven progressively less as they age. The Volpe model defines vehicle lifetime as the point at which less than 2 percent of the vehicles originally produced in a model year remain in service. Under this definition, passenger cars survive in the fleet for as long as 26 years, while light trucks can survive for up to 37 years. Of course, any individual vehicle is unlikely to survive to these maximum ages; the typical lifetimes for passenger cars and light trucks produced during recent model years are approximately 12 and 14 years, respectively.

2.3.3 Energy Market Forecast Assumptions

In this EIS, NHTSA uses projections of energy consumption and supply derived from the EIA, a DOE agency that collects and provides official energy statistics for the United States. EIA is the primary source of data that government agencies and private firms use to analyze and model energy systems.

Every year, EIA issues projections of energy consumption and supply for the United States (AEO) and the world (International Energy Outlook [IEO]). EIA reports energy forecasts through 2035 for consumption and supply by energy fuel source, sector, and geographic region. The model used to formulate EIA projections incorporates all federal and state laws and regulations in force at the time of modeling. Potential legislation and laws under debate in Congress are not included.

In this EIS, unless otherwise noted, NHTSA uses projections of energy consumption and supply based on the 2011 IEO and 2011 AEO Reference Case.[15] The AEO 2011 projections reflect the impact of market forces, MY 2012–2016 CAFE standards, and assumed increases in MY 2017–2020 CAFE standards to reflect EISA's requirement that the light-duty fleet achieve a

[15] The Reference Case is a scenario under which forecasts are made with the following assumptions: (i) all current laws and regulations, including sunset clauses, remain unchanged throughout the forecast period, (ii) an annual average real Gross Domestic Product growth rate of 2.7 percent, (iii) an annual average growth rate in non-farm business and employment productivity of 2.0 percent, (iv) an annual average growth rate in non-farm business and employment of 1.0 percent, and (v) an annual average growth rate in the price of crude oil delivered to refineries in the United States of 2.6 percent. This price of crude oil is expected to reach $113.70 per barrel in 2009 U.S. dollars in 2030. *See* EIA 2011a, "Macroeconomic Growth Cases, the *Reference Case*;" EIA 2011a, "Table A12. Petroleum Product Prices, AEO 2011 Reference Case (2009 dollars per gallon, unless otherwise noted)."

combined fuel economy of 35 mpg by MY 2020. The AEO 2011 forecast does not reflect the impacts of the MY 2014–2018 HD Fuel Efficiency Improvement Program (adopted after the release of AEO 2011) or proposed MY 2017–2025 CAFE standards that exceed the 35 mpg EISA requirement for 2020. The AEO 2011 forecast assumes that CAFE standards are held constant after MY 2020, with forecasted fuel economy improvements after 2020 based on economic cost-benefit analysis from a consumer's and manufacturers' perspective, which does not include energy security and GHG emissions reduction benefits (EIA 2011b). NHTSA's CAFE requirements are established in consideration of a cost-benefit assessment from a societal perspective, which does include energy security and GHG emissions reduction benefits.

2.3.4 Approach to Scientific Uncertainty and Incomplete Information

CEQ regulations recognize that many federal agencies encounter limited information and substantial uncertainties when analyzing the potential environmental impacts of their actions. Accordingly, the regulations provide agencies with a means of formally acknowledging incomplete or unavailable information in NEPA documents. Where "information relevant to reasonably foreseeable significant adverse impacts cannot be obtained because the overall costs of obtaining it are exorbitant or the means to obtain it are not known," the regulations require an agency to include in its NEPA document:

1. A statement that such information is incomplete or unavailable
2. A statement of the relevance of the incomplete or unavailable information to evaluating reasonably foreseeable significant adverse impacts on the human environment
3. A summary of existing credible scientific evidence relevant to evaluating the reasonably foreseeable significant adverse impacts on the human environment
4. The agency's evaluation of such impacts based on theoretical approaches or research methods generally accepted in the scientific community

40 CFR § 1502.22(b).

Throughout this EIS, NHTSA uses this mechanism – acknowledging incomplete or unavailable information – to address areas for which the agency cannot develop a credible estimate of the potential environmental impacts of the Proposed Action or reasonable alternatives.[16] NHTSA recognizes that information about the potential environmental impacts of changes in emissions of CO_2 and other GHGs and associated changes in temperature, including those expected to result from the proposed rule, is incomplete. NHTSA relies on the Intergovernmental Panel on Climate Change (IPCC) 2007 Fourth Assessment Report (IPCC 2007a, 2007b, 2007c, 2007d, 2007e) as a recent "summary of existing credible scientific evidence which is relevant to evaluating the reasonably foreseeable significant adverse impacts on the human environment." 40 CFR § 1502.22(b)(3).

2.4 Resource Areas Affected and Types of Emissions

The major resource areas affected by the proposed standards are energy, air quality, and climate. Chapter 3 describes the affected environment for energy and energy impacts under

[16] Relying on these provisions is appropriate when an agency is performing a NEPA analysis that involves potential environmental impacts resulting from carbon dioxide (CO_2) emissions (*e.g., Mayo Found. v. Surface Transp. Bd.*, 472 F.3d 545, 555 (8th Cir. 2006)).

each alternative. Chapters 4 and 5 describe the affected environments and impacts for air quality and climate change, respectively.

2.4.1 Types of Emissions

Emissions, including GHGs, criteria pollutants, and airborne toxics, are categorized for purposes of this analysis as either “downstream” or “upstream.” Downstream emissions are released from a vehicle while it is in operation, parked, or being refueled, and consist of tailpipe exhaust, evaporative emissions of volatile compounds from the vehicle’s fuel storage and delivery system, and particulates generated by brake and tire wear. All downstream emissions were estimated using the most recent version of EPA’s Motor Vehicle Emission Simulator (MOVES2010a) model (EPA 2010a). Upstream emissions related to the Proposed Action are those associated with crude-petroleum extraction and transportation, and with the refining, storage, and distribution of transportation fuels. Upstream emissions from EVs also include emissions associated with using primary fuels (e.g., coal, natural gas, nuclear) to generate the electricity needed to run these vehicles. The amount of emissions created when generating electricity depends on the composition of fuels used for generation, which varies regionally. NHTSA estimated both domestic and international upstream emissions of CO_2, and only domestic upstream emissions of criteria air pollutants and airborne toxics. Estimates of all upstream emissions were based on the Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET, version 1.8) model developed by the DOE Argonne National Laboratory (Argonne 2002), and modified by EPA as described in the TSD.[17] Sections 2.4.1.1 and 2.4.1.2 describe analytical methodologies and assumptions used in this EIS for emissions modeling, including the impact of the rebound effect. Chapters 4 and 5 discuss modeling issues related specifically to the air quality and climate change analyses, respectively.

2.4.1.1 Downstream Emissions

Most downstream emissions are exhaust (tailpipe) emissions. The basic method used to estimate tailpipe emissions entails multiplying activity levels of passenger cars and light trucks by emission factors for each vehicle type measured in grams of each pollutant emitted per unit of activity.

The Volpe model uses emission factors developed by EPA using its MOVES2010a emission model (EPA 2010a). MOVES incorporates EPA’s updated estimates of real-world emissions from passenger cars and trucks and accounts for emission control requirements on exhaust emissions and evaporative emissions, including the Tier 2 Vehicle & Gasoline Sulfur Program (EPA 2011a) and the mobile source air toxics (MSAT) rule (EPA 2007a). The MOVES2010a database includes default distributions of vehicles by type and age, vehicle activity levels, vehicle characteristics, national-level fuel quality estimates, and other key parameters used to generate emission estimates. In modeling downstream emissions of particulate matter 2.5 microns or less in diameter ($PM_{2.5}$), EPA included emissions from brake and tire wear in addition to exhaust. MOVES2010a defaults were used for all other parameters to estimate tailpipe and other components of downstream emissions under the No Action Alternative.

NHTSA’s and EPA’s emissions analysis methodology assumes that no reduction in tailpipe emissions of criteria pollutants or air toxics will occur solely as a consequence of improvements

[17] A new version of GREET was released in October 2011, after the analysis in this Draft EIS was completed. NHTSA will assess the new version of GREET for potential use in the Final EIS.

in fuel economy that are not already accounted for within MOVES. In its emissions calculations, MOVES accounts for the amount of power required of the engine under different operating conditions such as vehicle weight, speed, and acceleration. Changes to the vehicle that result in reduced engine load, such as from more efficient drivetrain components, improved aerodynamics, and lower rolling-resistance tires, are thus already reflected in the MOVES calculations of both fuel economy and emissions. Because the proposed standards are not intended to dictate the design and technology choices manufacturers must make to comply, a manufacturer could employ technologies that increase fuel economy (and therefore reduce CO_2 and SO_2 emissions), while at the same time increasing emissions of other criteria pollutants or air toxics, as long as the manufacturer's production still meets both the fuel economy standards and prevailing EPA emission standards. Depending on which strategies are pursued to meet the increased fuel economy standards, emissions of these other pollutants could increase or decrease.

In calculating emissions, two sets of units can be used depending on how activity levels are measured:

- Activity expressed as VMT, and emission factors expressed as grams emitted per VMT.
- Activity expressed as fuel consumption in gallons, and emission factors expressed as grams emitted per gallon of fuel.

Considering both sets of units provides insight into how emissions of different GHGs and air pollutants vary with fuel economy and VMT.

Almost all of the carbon in fuels that are combusted in vehicle engines is oxidized to CO_2, and essentially all of the sulfur content of the fuel is oxidized to SO_2. As a result, emissions of CO_2 and SO_2 are constant in terms of grams emitted per gallon of fuel; their total emissions vary directly with the total volume of fuel used, and inversely with fuel economy (mpg). Thus, emission factors for CO_2 and SO_2 are not constant in terms of grams emitted per VMT of a specific vehicle, because fuel economy – and thus the amount of fuel used per VMT – varies with vehicle operating conditions.

In contrast to CO_2 and SO_2, downstream emissions of the other criteria pollutants and the toxic air pollutants are not constant in terms of grams emitted per gallon of fuel. This is because the formation of these pollutants is affected by the continually varying conditions of engine and vehicle operation dictated by the amount of power required, and by the type and efficiency of emission controls with which a vehicle is equipped. For other criteria pollutants and airborne toxics, MOVES calculates emission rates individually for specific combinations of inputs, including various vehicle types and ages, as well as other key parameters noted above.

MOVES then uses these emission rates to calculate total emissions of each pollutant for each individual combination of inputs (e.g., automobiles of a given age), and aggregates the results to derive total emissions of each pollutant for the entire vehicle population of interest (e.g., automobiles of all ages). Finally, dividing total emissions of each pollutant by total VMT produces an aggregate or composite emission factor (in grams per VMT) for that entire vehicle population. This composite emission factor remains constant as long as none of the MOVES inputs, including the composition of the vehicle population by vehicle type and the age distributions of different types of vehicles, changes. Accordingly, for a given vehicle population and composition, calendar year, and fuel economy level (determined by the CAFE standards), the emissions for all pollutants (including SO_2) are constant on a per-VMT basis and the total emissions vary directly with VMT.[18]

The agencies assume that as a result of the rebound effect, total VMT would increase slightly with increases in fuel economy, thereby causing tailpipe emissions of each air pollutant generated by vehicle use (rather than by fuel consumption) to increase in proportion to this increase in VMT. However, emissions on a per-VMT basis as calculated by MOVES could decline as a result of increased fuel economy, as discussed above.[19] If the increases in fuel consumption and emissions associated with the higher VMT (due to the rebound effect) are small compared to the decrease in fuel use (due to increased fuel economy), then the net result can be a reduction in total emissions.

2.4.1.2 Upstream Emissions

Volpe also estimated the impacts of the action alternatives on upstream emissions associated with petroleum extraction and transportation, and the refining, storage, and distribution of transportation fuels, as well as upstream emissions associated with generation of electricity for EVs. NHTSA and EPA project that the proposed standards will lead to reductions in upstream emissions from fuel production and distribution, because the total amount of fuel used by passenger cars and light trucks will decline under the proposed standards compared to the No Action Alternative. To the extent that any of the action alternatives would lead to an increase in use of EVs, upstream emissions associated with charging EVs could increase as a result of adopting that alternative. These increases would offset part of the reduction in upstream emissions resulting from reduced production of motor vehicle fuels. The net effect on national upstream emissions would depend on the relative magnitudes of the reductions in motor fuel production and the increases in electric power production, and would vary by pollutant. (*See* Section 6.2.2 for a discussion of emissions differences between conventional and EVs).

Although the rebound effect is assumed to result in identical percentage increases in VMT and downstream emissions from vehicle use in all regions of the United States, the associated changes in upstream emissions are expected to vary among regions, because fuel refining and storage facilities and electric power plants are not uniformly distributed across the country. Therefore, an individual geographic region could experience either a net increase or a net decrease in emissions of each pollutant due to the proposed fuel economy standards, depending on the relative magnitudes of the increase in emissions from vehicle use and electric power production and the decline in emissions resulting from reduced fuel production and distribution in that geographic region.

NHTSA estimated upstream emissions using the GREET model (version 1.8a) developed by DOE Argonne National Laboratory (Argonne 2002). For the analysis of direct and indirect

[18] The emission rates calculated by EPA for this analysis using MOVES include only those components of emissions expected to vary in response to changes in vehicle use. These include exhaust emissions associated with starting and operating vehicles, as well as particulate emissions resulting from brake and tire wear. However, they *exclude* emissions associated with activities such as vehicle storage, because those do not vary directly with vehicle use. Thus, the estimates of aggregate emissions reported for the No Action Alternative and action alternatives do not represent total emissions of each pollutant under any of those alternatives. However, the difference in emissions of each pollutant between any action alternative and the No Action Alternative does represent an accurate estimate of the change in total emissions of that pollutant that would result from adopting that action alternative.

[19] However, the agencies believe that increased production of EVs may not reduce average emissions on a per-VMT basis, because producers of EVs may allow the per-VMT emission rates of their conventionally fueled vehicles to increase to levels that still enable them to comply with EPA regulations on manufacturers' fleet average emission rates. This response would leave each manufacturer's average emissions per VMT unchanged, regardless of the extent to which it produced EVs as a compliance strategy.

environmental impacts, NHTSA and EPA assumed that the only effects of increased fuel economy on upstream emissions result from changes in the volumes of gasoline and diesel produced and consumed, and the number of EVs included under each action alternative. In contrast, the agencies assumed that the proportions of total fuel production and consumption represented by ethanol and other renewable fuels (such as biodiesel) under each of the action alternatives would be identical to those under the No Action Alternative.

The GREET model used to project impacts analyzed in this EIS was last modified by EPA for use in analyzing its 2009 Renewable Fuel Standard 2 (RFS2) proposed rulemaking. The updates EPA made to the GREET model for purposes of that rulemaking include updated crude oil and gasoline transport emission factors that account for recently adopted emission standards such as the Tier 4 diesel truck standards (adopted in 2001) and the locomotive and commercial marine standards (finalized in 2008). In addition, EPA modified the GREET model to add emission factors for the following air toxics: acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde. NHTSA used data from the EPA-modified GREET model for the Volpe model calculations.

Actual calculations of the impacts of decreased fuel production on total emissions of each pollutant use the volumes of petroleum-based fuels estimated to be produced and consumed under each action alternative, together with emission factors for individual phases of the fuel production and distribution process derived from GREET. The emission factors derived from GREET (expressed as grams of pollutant per million British thermal units of fuel energy content) for each phase of the fuel production and distribution process were multiplied by the volumes of different types of fuel produced and distributed under each action alternative to estimate the resulting changes in emissions during each phase of fuel production and distribution. These emissions were added together to get the total emissions from fuel production and distribution resulting from each action alternative. This process was repeated for each alternative, and the change in upstream emissions of each pollutant resulting from each action alternative was estimated as the difference between upstream emissions of that pollutant under the action alternative and its upstream emissions under the No Action Alternative.

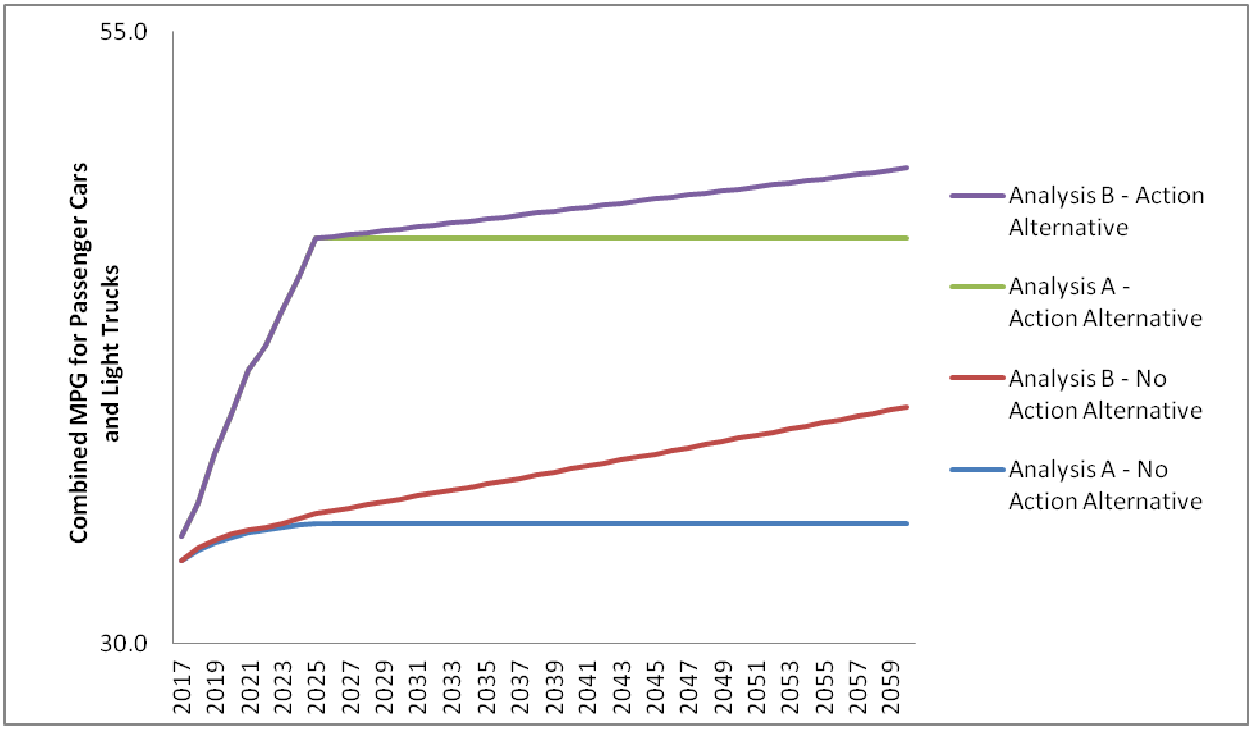
2.5 Direct and Indirect versus Cumulative Impacts

CEQ NEPA implementing regulations require agencies to consider the direct and indirect effects and cumulative impacts of major federal actions. CEQ regulations define direct effects as those that “are caused by the action and occur at the same time and place” and indirect effects as those that “are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable.” 40 CFR § 1508.8. CEQ regulations define cumulative impacts as “the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions.” 40 CFR § 1508.7.

To derive the impacts of the action alternatives reported throughout this document, NHTSA compares the action alternatives to the No Action Alternative. As described above, based on the considerable uncertainty regarding whether and to what degree fleetwide fuel economy would change in the absence of agency action, NHTSA has included two separate analyses of the direct and indirect impacts of the proposal – one that assumes essentially no change in the average level of fuel economy under the No Action alternative and in the action alternatives following the rulemaking period (Analysis A), and a second analysis assuming market-based growth both in the No Action Alternative and in the action alternatives following the rulemaking period (Analysis B). Both Analyses account for the direct effects of the rule (i.e., fuel economy improvements in MYs 2017–2025) and the indirect effects of the rule (i.e., fuel economy levels in MY 2026 and after that would not have occurred but for the agency action).

Figure 2.5-1 is a representative illustration of the fuel economy levels that would be obtained based on the underlying assumptions for the two perspectives (Analysis A and Analysis B). The bottom lines indicate the No Action Alternative for Analysis A and Analysis B, while the top lines illustrate action alternatives for Analysis A and Analysis B.

Figure 2.5-1. No Action and Action Alternative Representations for Analysis A and Analysis B



Under Analysis A, the direct and indirect impacts of the proposed rule stem from the fuel economy improvements represented in Figure 2.5-2-A. Under Analysis B, direct and indirect impacts of the proposed rule stem from the fuel economy improvements represented in Figure 2.5-2-B.

To analyze cumulative impacts of the proposed rule, the agency accounted for the fuel economy improvements that result directly or indirectly from the proposed rule in addition to reasonably foreseeable improvements in fuel economy stemming from other sources – specifically, fuel economy improvements that would result from actions taken by manufacturers without the agency's action. Figure 2.5-3 illustrates fuel economy improvements by manufacturers due both directly and indirectly to this rule, as well as those due to other potential market forces (i.e., increased consumer demand for fuel economy). The environmental benefits stemming from all of these improvements beyond those needed to comply with the MY 2016 CAFE standards thus takes into account the past, present, and reasonably foreseeable future actions of both the Federal Government (in the form of CAFE standards) and manufacturers (in response to market demands for increased fuel economy). The cumulative impacts analysis in future chapters demonstrates the environmental impacts (including impacts to energy, air quality, and climate) resulting from both CAFE standards and other fuel economy improvements that are reasonably foreseeable.

Figure 2.5-2-A. Representation of Direct and Indirect Impacts for Analysis A

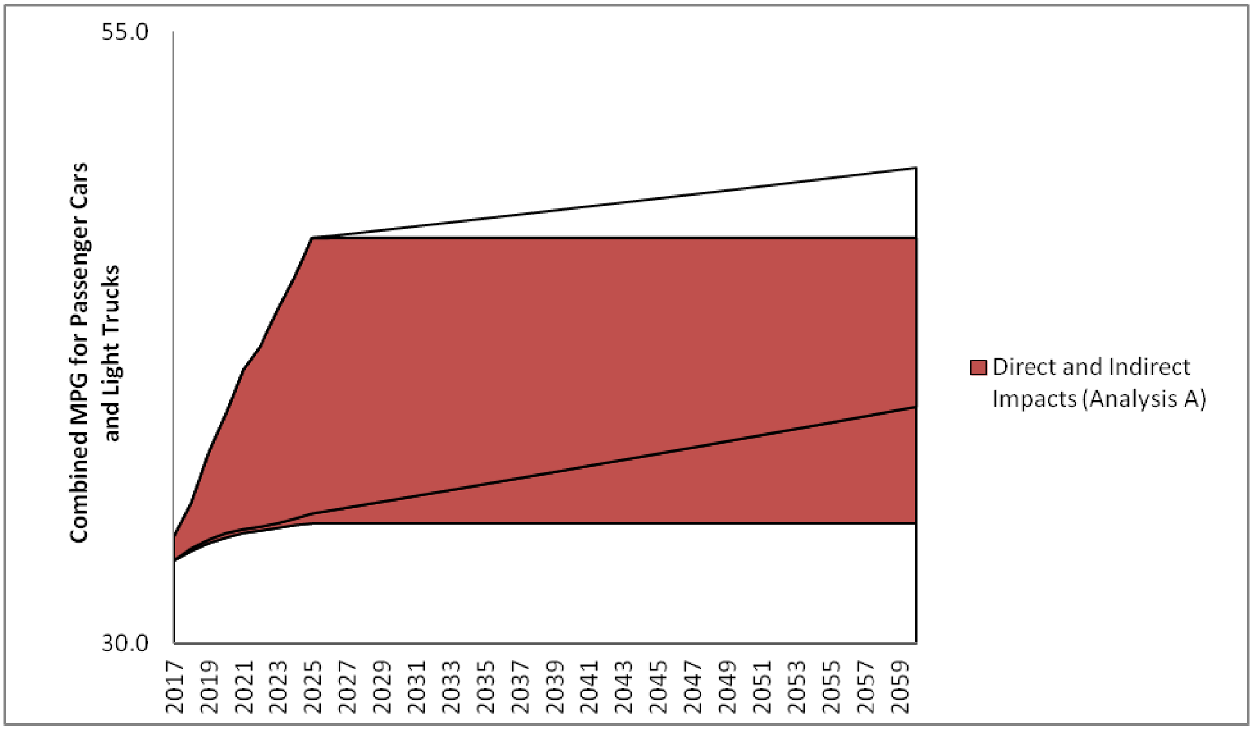


Figure 2.5-2-B. Representation of Direct and Indirect Impacts for Analysis B

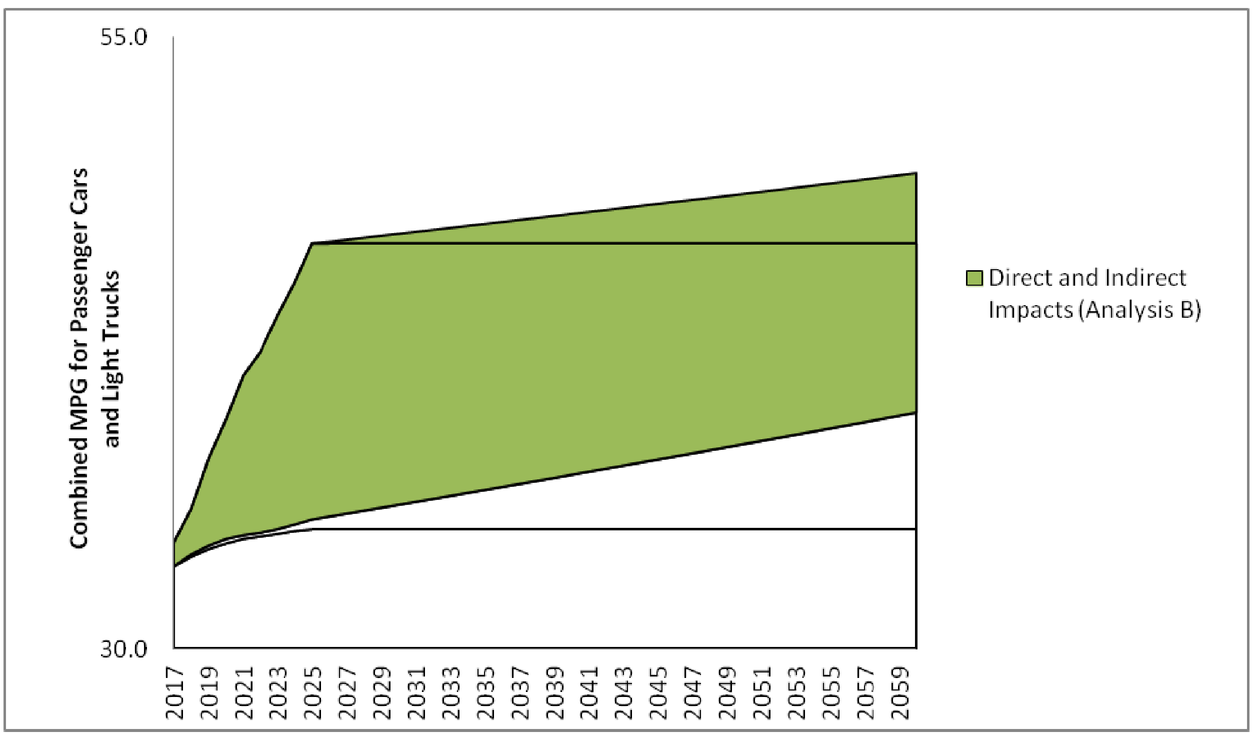
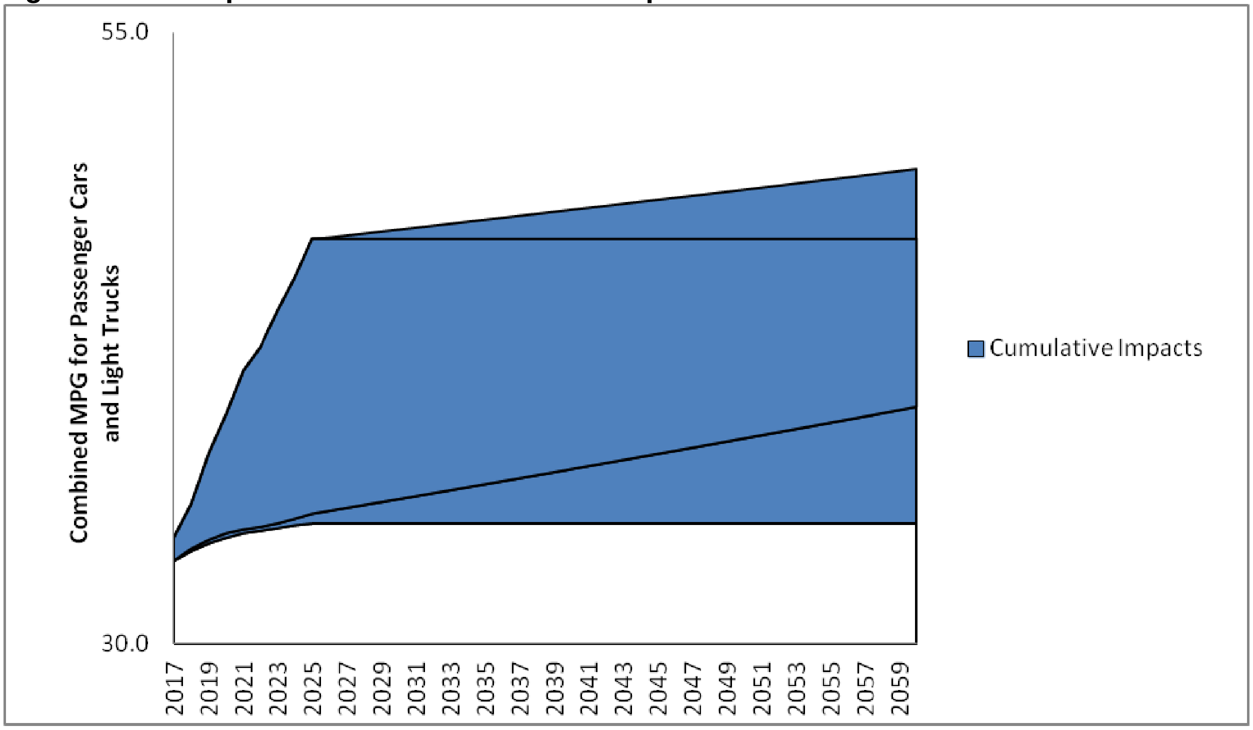


Figure 2.5-3. Representation of Cumulative Impacts



2.6 Comparison of Alternatives

The CEQ NEPA implementing regulations direct federal agencies to present in an EIS "the environmental impacts of the proposal and the alternatives in comparative form, thus sharply defining the issues and providing a clear basis for choice among options by the decisionmaker and the public."[20] This section summarizes and compares the direct, indirect, and cumulative impacts of the Proposed Action and alternatives on energy, air quality, and climate, as presented in Chapters 3, 4, and 5. No quantifiable, alternative-specific effects were identified for the other resource areas discussed in Chapters 6 and 7 of this EIS, so they are not summarized here.

In the alternatives analyzed in this EIS, the growth in the number of passenger cars and light trucks in use throughout the United States and in the annual VMT by these vehicles outpaces improvements in economy under each action alternative, resulting in projected increases in total fuel consumption by passenger cars and light trucks. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from passenger cars and light trucks. NHTSA estimates that the proposed CAFE standards would reduce fuel consumption and CO_2 emissions from the future levels that would otherwise occur in the absence of the new CAFE standards (i.e., fuel consumption and CO_2 emissions under the No Action Alternative).

[20] *See* 40 CFR § 1502.14.

2.6.1 Direct and Indirect Impacts

This section compares the direct and indirect impacts of the No Action Alternative and the three action alternatives on energy, air quality, and climate, as presented in Chapters 3, 4, and 5. Table 2.6.2-1-A presents results for Analysis A, which assumes no increase in new vehicle fuel economy under the No Action Alternative beginning in MY 2017 and no additional increases in fuel economy under the action alternatives after MY 2025. Table 2.6.2-1-B presents results for Analysis B, which assumes increases in new vehicle fuel economy under the No Action Alternative beginning in MY 2017 and additional increases in fuel economy under the action alternatives after MY 2025.

Table 2.6.1-1-A. Direct and Indirect Impacts, Analysis A[a,b]

		Alternative 1 No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Energy	**Total Combined U.S. Passenger Car and Light Truck Fuel Consumption for 2017–2060**	7,092 billion gallons	6,361 billion gallons	5,860 billion gallons	5,216 billion gallons
Energy	**Total Combined U.S. Passenger Car and Light Truck Fuel Savings Compared to No Action for 2017–2060**	–	731 billion gallons	1,232 billion gallons	1,877 billion gallons
Air Quality	**Criteria Air Pollutant Emissions Reductions in 2040 Compared to No Action**	–	Emissions of most criteria pollutants (NO_x, $PM_{2.5}$, SO_2, and VOCs) will decrease compared to the No Action Alternative, while emissions of CO will increase.	Emissions of most criteria pollutants (NO_x, $PM_{2.5}$, SO_2, and VOCs) will decrease compared to the No Action Alternative, while CO will increase slightly. The increase in CO emissions will be less than the increase under Alternative 2, while the decreases in other emissions will be greater than the decreases under Alternative 2.	Emissions of all criteria pollutants (CO, NO_x, $PM_{2.5}$, SO_2 and VOCs) will decrease compared to the No Action Alternative. The decreases in emissions will be greater than the decreases under Alternative 3, except for SO_2, which will decrease less than the decrease under Alternative 3.
Air Quality	**Toxic Air Pollutant Emissions Reductions in 2040 Compared to No Action**	–	Emissions of benzene and DPM will decrease compared to the No Action Alternative, while emissions of acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde will increase.	Emissions of benzene and DPM will decrease compared to the No Action Alternative; these decreases will be greater than the decreases under Alternative 2. Emissions of acetaldehyde, acrolein, and formaldehyde will increase; these increases will be greater than the increases under Alternative 2. Emissions of 1,3-butadiene will remain roughly equal to those under the No Action Alternative.	Emissions of acetaldehyde, 1,3-butadiene, benzene and DPM will decrease compared to the No Action Alternative; these will be the greatest decreases of all alternatives for acetaldehyde, benzene, and 1,3-butadiene. Emissions of acrolein and formaldehyde will increase; these increases will be greater than the increases under Alternative 3.

Table 2.6.1-1-A. Direct and Indirect Impacts, Analysis A[a,b] (continued)

		Alternative 1 No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Air Quality (cont'd)	**Reductions in Premature Mortality Cases and Work-loss Days in 2040** (values within ranges depend on assumptions used)	–	Premature mortality: reduced by 223 to 570 cases Work-loss days: reduced by 24,385 days	Premature mortality: reduced by 380 to 970 cases Work-loss days: reduced by 41,650 days	Premature mortality: reduced by 500 to 1,278 cases Work-loss days: reduced by 55,746 days
	Range of Monetized Health Benefits in 2040 Compared to No Action Under a 3% and 7% Discount Rate (values within ranges depend on assumptions used)	–	3%: $1.7 billion to $4.3 billion 7%: $1.5 billion to $3.9 billion	3%: $3.0 billion to $7.3 billion 7%: $2.7 billion to $6.6 billion	3%: $3.9 billion to $9.6 billion 7%: $3.6 billion to $8.8 billion
Climate	**Total GHG Emissions from U.S. Passenger Cars and Light Trucks for 2017– 2100**	166,500 $MMTCO_2$	147,300 $MMTCO_2$ (19,100 $MMTCO_2$ [11%] less than the No Action Alternative)	134,300 $MMTCO_2$ (32,200 $MMTCO_2$ [19%] less than the No Action Alternative)	119,000 $MMTCO_2$ (47,500 $MMTCO_2$ [29%] less than the No Action Alternative)
	Atmospheric Carbon Dioxide Concentrations in 2100	784.9 ppm	783.0 ppm (1.8 ppm less than the No Action Alternative)	781.8 ppm in 2100 (3.1 ppm less than the No Action Alternative)	780.3 ppm (4.5 ppm less than the No Action Alternative)
	Increase in Global Mean Surface Temperature by 2100	3.064 °C (5.515 °F)	3.058 °C (5.504 °F) (0.006 °C [0.011 °F] less than the No Action Alternative)	3.053 °C (5.495 °F) (0.011 °C [0.020 °F] less than the No Action Alternative)	3.048 °C (5.486 °F) (0.016 °C [0.029 °F] less than the No Action Alternative)
	Global Sea-level Rise by 2100	37.40 centimeters (14.72 inches)	37.34 centimeters (14.70 inches) (0.06 centimeter [0.024 inch] less than the No Action Alternative)	37.30 centimeters (14.68 inches) (0.10 centimeter [0.04 inch] less than the No Action Alternative)	37.25 centimeters (14.66 inches) (0.15 centimeter [0.06 inch] less than the No Action Alternative)
	Global mean Precipitation Increase by 2090	4.50%	4.49% (0.01% less than the No Action Alternative)	4.48% (0.02% less than the No Action Alternative)	4.48% (0.02% less than the No Action Alternative)

a. The numbers in this table have been rounded for presentation purposes. Therefore, the reductions might not reflect exact difference of the values in all cases.
b. °C = degrees Celsius; °F = degrees Fahrenheit; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons of carbon dioxide; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter 2.5 mircons diameter or less; ppm = parts per million; SO_2 = sulfur dioxide; VOCs = volatile organic compounds;

Table 2.6.1-1-B. Direct and Indirect Impacts, Analysis B[a,b]

		Alternative 1 No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Energy	**Total Combined U.S. Passenger Car and Light Truck Fuel Consumption for 2017–2060**	6,421 billion gallons	5,975 billion gallons	5,583 billion gallons	4,964 billion gallons
Energy	**Total Combined U.S. Passenger Car and Light Truck Fuel Savings Compared to No Action for 2017–2060**	–	446 billion gallons	838 billion gallons	1,457 billion gallons
Air Quality	**Criteria Air Pollutant Emissions Reductions in 2040 Compared to No Action**	–	Emissions of most criteria pollutants (NO_x, $PM_{2.5}$, SO_2, and VOCs) will decrease compared to the No Action Alternative, while emissions of CO will increase.	Emissions of all criteria pollutants (CO, NO_x, $PM_{2.5}$, SO_2, and VOCs) will decrease compared to the No Action Alternative. The decreases in emissions will be greater than the decreases under Alternative 2, except for NO_x emissions, which will decrease less than the decrease under Alternative 2.	Emissions of most criteria pollutants (CO, NO_x, $PM_{2.5}$, SO_2 and VOCs) will decrease compared to the No Action Alternative, while SO_2 emissions will increase. The decreases in emissions will be greater than the decreases under Alternative 3. This is the only alternative under which SO_2 emissions will increase.
Air Quality	**Toxic Air Pollutant Emissions Reductions in 2040 Compared to No Action**	–	Emissions of benzene and DPM will decrease compared to the No Action Alternative, while emissions of acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde will increase.	Emissions of benzene and DPM will decrease compared to the No Action Alternative; the decrease in benzene emissions will be greater than the decrease under Alternative 2. Emissions of acetaldehyde, acrolein, and formaldehyde will increase; these increases will be greater than the increases udner Alternative 2. Emissions of 1,3-butadiene will remain roughly equal to those under the No Action Alternative.	Emissions of acetaldehyde, benzene, and 1,3-butadiene will decrease compared to the No Action Alternative; these will be the greatest decreases of all alternatives for acetaldehyde, benzene, and 1,3-butadiene. Emissions of acrolein, DPM, and formaldehyde will increase; these increases will be greater than the increases under Alternative 3.

Table 2.6.1-1-B. Direct and Indirect Impacts, Analysis B[a,b] (continued)

		Alternative 1 No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Air Quality (cont'd)	**Reductions in Premature Mortality Cases and Work-loss Days in 2040** (values within ranges depend on assumptions used)	–	Premature mortality: reduced by 160 to 409 cases Work-loss days: reduced by 17,466 days	Premature mortality: reduced by 301 to 770 cases Work-loss days: reduced by 33,045 days	Premature mortality: reduced by 456 to 1,166 cases Work-loss days: reduced by 50,971 days
	Range of Monetized Health Benefits in 2040 Compared to No Action Under a 3% and 7% Discount Rate (values within ranges depend on assumptions used)	–	3%: $1.3 billion to $3.1 billion 7%: $1.1 billion to $2.8 billion	3%: $2.4 billion to $5.8 billion 7%: $2.1 billion to $5.3 billion	3%: $3.6 billion to $8.8 billion 7%: $3.3 billion to $8.0 billion
Climate	**Total GHG Emissions from U.S. Passenger Cars and Light Trucks for 2017–2100**	139,500 $MMTCO_2$	130,900 $MMTCO_2$ (8,600 $MMTCO_2$ [6%] less than the No Action Alternative)	122,200 $MMTCO_2$ (17,300 $MMTCO_2$ [12%] less than the No Action Alternative)	108,200 $MMTCO_2$ (31,300 $MMTCO_2$ [22%] less than the No Action Alternative)
	Atmospheric Carbon Dioxide Concentrations in 2100	784.9 ppm	784.1 ppm (0.8 ppm less than the No Action Alternative)	783.3 ppm in 2100 (1.6 ppm less than the No Action Alternative)	781.9 ppm (3.0 ppm less than the No Action Alternative)
	Increase in Global Mean Surface Temperature by 2100	3.064 °C (5.515 °F)	3.061 °C (5.509 °F) (0.003 °C [0.005 °F] less than the No Action Alternative)	3.058 °C (5.504 °F) (0.006 °C [0.011 °F] less than the No Action Alternative)	3.053 °C (5.495 °F) (0.011 °C [0.020 °F] less than the No Action Alternative)
	Global Sea-level Rise by 2100	37.40 centimeters (14.72 inches)	37.37 centimeters (14.71 inches) (0.03 centimeter [0.012 inch] less than the No Action Alternative)	37.34 centimeters (14.70 inches) (0.06 centimeter [0.024 inch] less than the No Action Alternative)	37.29 centimeters (14.68 inches) (0.11 centimeter [0.043 inch] less than the No Action Alternative)
	Global mean Precipitation Increase by 2090	4.50%	4.49% (0.00% less than the No Action Alternative)	4.49% (0.01% less than the No Action Alternative)	4.48% (0.02% less than the No Action Alternative)

a. The numbers in this table have been rounded for presentation purposes. Therefore, the reductions might not reflect exact difference of the values in all cases.
b. °C = degrees Celsius; °F = degrees Fahrenheit; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons of carbon dioxide; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter 2.5 mircons diameter or less; ppm = parts per million; SO_2 = sulfur dioxide; VOCs = volatile organic compounds.

2.6.2 Cumulative Impacts

This section compares the cumulative impacts of the various action alternatives on energy, air quality, and climate, as presented in Chapters 3, 4, and 5. By forecasting future fuel economy improvements resulting directly or indirectly from the action alternatives, in addition to other reasonably foreseeable fuel economy improvements, and comparing the benefits of those new vehicles to a passenger car and light truck fleet comprised increasingly of vehicles complying only with MY 2016 standards, this analysis accounts for the overall benefits of past, present, and reasonably foreseeable fuel economy increases. Table 2.6.2-2 presents the results of this analysis.

Table 2.6.2-1. Cumulative Impacts[a,b]

		Alternative 1 No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Energy	**Total Combined U.S. Passenger Car and Light Truck Fuel Consumption for 2017–2060**	7,092 billion gallons	5,975 billion gallons	5,583 billion gallons	4,964 billion gallons
Energy	**Total Combined U.S. Passenger Car and Light Truck Fuel Savings Compared to No Action for 2017–2060**	–	1,117 billion gallons	1,509 billion gallons	2,128 billion gallons
Air Quality	**Criteria Air Pollutant Emissions Reductions in 2040 Compared to No Action**	–	Emissions of most criteria pollutants (NO_x, $PM_{2.5}$, SO_2, and VOCs) will decrease compared to the No Action Alternative, while emissions of CO will increase.	Emissions of most criteria pollutants (NO_x, $PM_{2.5}$, SO_2, and VOCs) will decrease compared to the No Action Alternative, while CO emissions will increase. Emissions decreases will be greater than the decreases under Alternative 2, except for that of NO_x, which will be less than the decrease under Alternative 2. The increase in CO emissions will be less than the increase under Alternative 2.	Emissions of all criteria pollutants (CO, NO_x, $PM_{2.5}$, SO_2 and VOCs) will decrease compared to the No Action Alternative. The decreases in emissions will be greater than the decreases under Alternative 3, except for SO_2, which will decrease less than the decreases under Alternatives 2 and 3.

Table 2.6.2-1. Cumulative Impacts[a,b] (continued)

		Alternative 1 No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Air Quality (cont'd)	**Toxic Air Pollutant Emissions Reductions in 2040 Compared to No Action**	–	Emissions of benzene and DPM will decrease compared to the No Action Alternative, while emissions of acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde will increase.	Emissions of benzene and DPM will decrease compared to the No Action Alternative; this decrese will be greater than the decrease under Alternative 2 for Benzene, and less than the decrease under Alternative 2 for DPM. Emissions of acetaldehyde, acrolein, and formaldehyde will increase; these increases will be greater than the increases under Alternative 2. Emissions of 1,3-butadiene will remain roughly equal to those under the No Action Alternative.	Emissions of acetaldehyde, benzene, 1,3-butadiene, and DPM will decrease compared to the No Action Alternative; these will be the greatest decreases of all alternatives for acetaldehyde, benzene, and 1,3-butadiene, and the smallest decrease for DPM. Emissions of acrolein and formaldehyde will increase; these increases will be greater than the increases under Alternative 3.
	Reductions in Premature Mortality Cases and Work-loss Days in 2040 (values within ranges depend on assumptions used)	–	Premature mortality: reduced by 309 to 790 cases Work-loss days: reduced by 33,795 days	Premature mortality: reduced by 450 to 1,151 cases Work-loss days: reduced by 49,374 days	Premature mortality: reduced by 605 to 1,548 cases Work-loss days: reduced by 67,300 days
	Range of Monetized Health Benefits in 2040 Compared to No Action Under a 3% and 7% Discount Rate (values within ranges depend on assumptions used)	–	3%: $2.4 billion to $5.9 billion 7%: $1.6 billion to $3.9 billion	3%: $3.5 billion to $8.7 billion 7%: $2.7 billion to $6.6 billion	3%: $4.8 billion to $11.7 billion 7%: $3.6 billion to $8.8 billion

Table 2.6.2-1. Cumulative Impacts[a,b] (continued)

		Alternative 1 No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Climate	**Total GHG Emissions from U.S. Passenger Cars and Light Trucks for 2017–2100**	166,500 $MMTCO_2$	130,900 $MMTCO_2$ (35,600 $MMTCO_2$ [21%] less than the No Action Alternative)	122,200 $MMTCO_2$ (44,200 $MMTCO_2$ [27%] less than the No Action Alternative)	108,200 $MMTCO_2$ (58,300 $MMTCO_2$ [35%] less than the No Action Alternative)
	Atmospheric Carbon Dioxide Concentrations in 2100	677.8 ppm	674.5 ppm (3.3 ppm less than the No Action Alternative)	673.7 ppm in 2100 (4.1 ppm less than the No Action Alternative)	672.4 ppm (5.4 ppm less than the No Action Alternative)
	Increase in Global Mean Surface Temperature by 2100	2.564 °C (4.615 °F)	2.551 °C (4.592 °F) (0.013 °C [0.023 °F] less than the No Action Alternative)	2.548 °C (4.586 °F) (0.016 °C [0.029 °F] less than the No Action Alternative)	2.542 °C (4.576 °F) (0.022 °C [0.040 °F] less than the No Action Alternative)
	Global Sea-level Rise by 2100	33.42 centimeters (13.16 inches)	33.32 centimeters (13.12 inches) (0.10 centimeter [0.04 inch] less than the No Action Alternative)	33.29 centimeters (13.11 inches (0.13 centimeter [0.05 inch] less than the No Action Alternative)	33.24 centimeters (13.09 inches) (0.18 centimeter [0.07 inch] less than the No Action Alternative)
	Global mean Precipitation Increase by 2090	3.89%	3.87% (0.02% less than the No Action Alternative)	3.87% (0.02% less than the No Action Alternative)	3.86% (0.03% less than the No Action Alternative)

a. The numbers in this table have been rounded for presentation purposes. Therefore, the reductions might not reflect exact difference of the values in all cases.
b. °C = degrees Celsius; °F = degrees Fahrenheit; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons of carbon dioxide; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter 2.5 mircons diameter or less; ppm = parts per million; SO_2 = sulfur dioxide; VOCs = volatile organic compounds.

CHAPTER 3 ENERGY

NHTSA's proposed standards would regulate fuel economy and therefore impact U.S. transportation sector fuel consumption. Transportation fuel comprises a large portion of total U.S. energy consumption and energy imports and has a significant impact on the functioning of the energy sector as a whole. Because automotive fuel consumption is expected to account for most U.S. net energy imports through 2035, the United States has the potential to achieve large reductions in imported oil use and, consequently, in the country's net energy imports during this time, by increasing the fuel economy of its fleet of passenger cars and light trucks.

Increasing the fuel economy of the light duty fleet is likely to have far-reaching impacts related to reducing U.S. dependence on foreign oil. Reducing dependence on energy imports is a key component of the President's March 30, 2011, *Blueprint for a Secure Energy Future*, which states that increasing transportation efficiency is an essential step toward that goal (White House 2011b). Similarly, the U.S. Department of Energy (DOE) acknowledges that vehicle efficiency has the greatest short- to mid-term impact on oil consumption (DOE 2011d).

In light of the U.S. energy sector and automotive fuel dynamic, this chapter discusses past, present, and forecast U.S. energy production and consumption and compares this affected environment to the potential energy impacts under NHTSA's Proposed Action. The chapter is organized as follows:

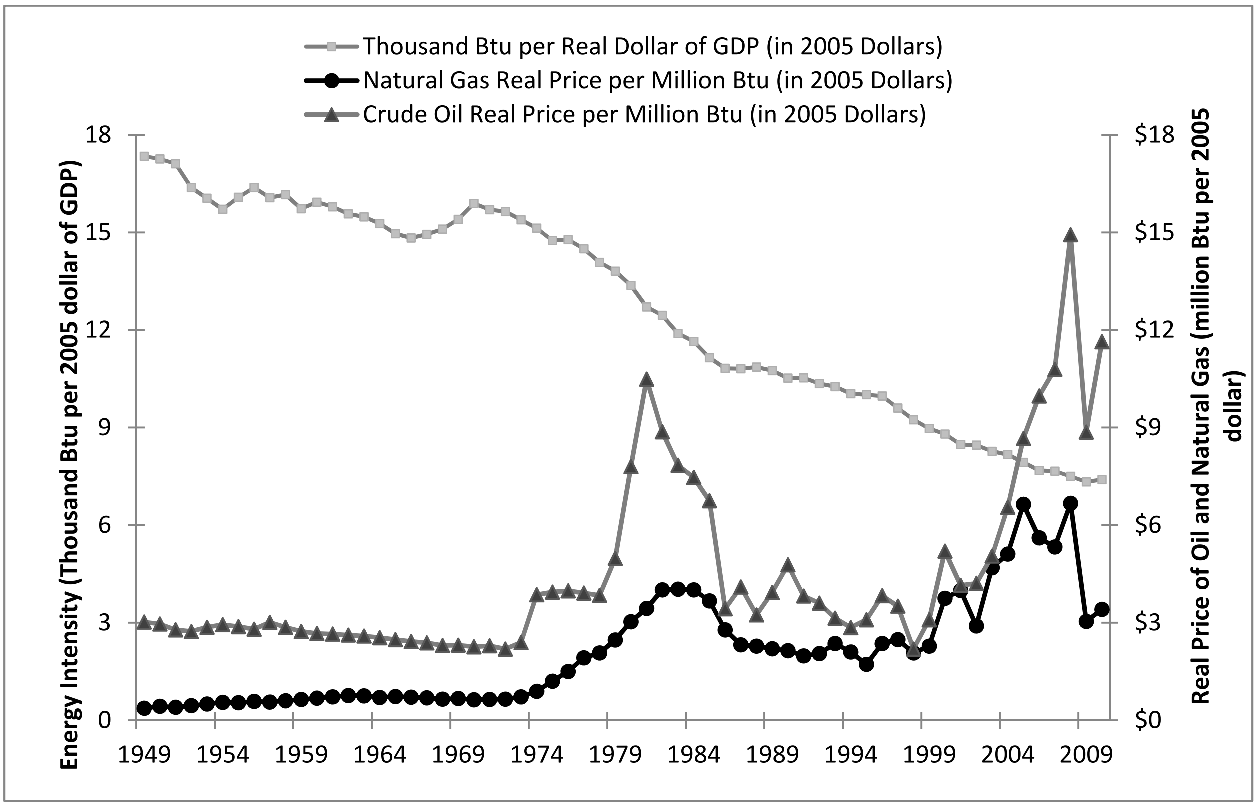
- Section 3.1 introduces energy intensity and consumption and describes how past and future trends in U.S. energy intensity relate to trends in the U.S. share of global energy consumption and U.S. energy imports.
- Section 3.2 describes the affected environment for U.S. energy production and consumption by primary fuel source (coal, natural gas, petroleum, and other) and consumption sectors (residential, commercial, industrial, and transportation), and how the light-duty vehicle sector impacts overall energy use.
- Section 3.3 describes the energy impacts of NHTSA's Proposed Action and alternatives, including direct and indirect (Section 3.3.1) and cumulative impacts (Section 3.3.2).

3.1 Introduction

Energy intensity is calculated as the sum of all energy supplied to an economy divided by its real (inflation-adjusted) Gross Domestic Product (GDP; the combined market price of all the goods and services produced in an economy at a given time). Through this calculation, energy intensity measures the efficiency at which energy is converted to GDP, with a high value indicating an inefficient conversion of energy to GDP and a lower value indicating a more efficient conversion. By providing the relationship between energy use and GDP instead of absolute energy use, energy intensity offers a better unit for looking at the energy efficiency of an economy than overall energy consumption. On the other hand, energy consumption is useful to determine absolute energy use, but does not indicate the efficiency at which this energy is used. For example, all things being equal, increased vehicle fuel efficiency will yield a lower energy intensity for a particular economy and a reduction in net fuel consumption, despite the fact that overall energy consumption might continue to increase. As discussed throughout this chapter, increasing CAFE standards have a great potential to contribute to decreases in U.S. energy intensity and net consumption. However, before analyzing the impacts of NHTSA's proposed standards on U.S. energy consumption, it is necessary to examine trends in U.S. energy intensity and consumption over time.

Figure 3.1-1 shows that the energy intensity of the U.S. economy (in thousand British thermal units [Btu] per real dollar of GDP) and the real price of fuel (in 2005 dollars per million Btu) did not change substantially from the early 1950s through the early 1970s. During that time, economic growth seemed to be directly linked to proportionate growth in energy supply. That relationship changed when the real price of oil and natural gas surged during the 1970s. As a result of many subsequent economic changes, the energy intensity of the U.S. economy was reduced by 54 percent over 4 decades (from 15,890 Btu per real dollar of GDP in 1970 to 7,330 Btu per real dollar of GDP in 2009), indicating an overall increase in the efficiency with which the U.S. uses energy (EIA 2011d). The 2011 Annual Energy Outlook (AEO) forecasts a continuing decline in U.S. energy intensity and a corresponding anticipated increase in the efficiency of energy use in the United States (falling to 4,445 Btu per real dollar of GDP by 2035) (EIA 2011a).

Figure 3.1-1. Energy Intensity and Real Price of Oil and Natural Gas 1949–2010[a,b]



a. Source: EIA 2011d, Table 1.5 Energy Consumption, Expenditures, and Emissions Indicators, 1949–2010 and Table 3.1 Fossil Fuel Production Prices, 1949–2010. Renewable Energy Consumption by Sector and Source.
b. Btu = British thermal unit; GDP = Gross Domestic Product.

The decline in U.S. energy intensity (and corresponding improvement in the economy's energy efficiency) over recent decades, combined with rapid economic growth and increased energy demand in many developing nations, has significantly reduced the U.S. share of international energy consumption. In 1980, the United States accounted for 27.6 percent of world energy consumption. By 2008, the U.S. share of global consumption had fallen to 20.4 percent. The 2011 International Energy Outlook forecasts a continuation of this trend, with the U.S. share of global consumption expected to fall to 18.1 percent by 2015, and 14.8 percent by 2035 (EIA 2011c).

Although both U.S. energy intensity and the U.S. share of global energy consumption have been declining in recent decades, total U.S. energy consumption has been increasing over that same time period. Therefore, although the U.S. continues to use energy more efficiently, the economy also continues to use more energy overall. However, this growth in energy consumption remains smaller than the growth in GDP, allowing energy intensity to continue to decline. For example, real GDP has increased from $4.3 trillion in 1970 to $13.0 trillion in 2009 (both in 2005 dollars), while U.S. energy consumption during that period has increased, although at a slower rate. Similarly, increases in U.S. energy consumption did not keep pace with increases in global energy consumption, resulting in a decline in the U.S. share of global energy consumption since 1980 despite overall increases in U.S. energy consumption during that period (EIA 2011d).

Most of the increase in U.S. energy consumption over the past decades has not come from increased domestic energy production, but instead from the increase in imports from foreign energy producers. Indeed, the United States has experienced a significant increase in net imports of crude oil and natural gas and a decrease in net exports of coal, while overall domestic energy production has increased at a much lower rate (EIA 2011a). From 1970 to 2009, U.S. net imports of crude oil increased 608 percent, net imports of natural gas increased 257 percent, and net exports of coal decreased 51 percent, all measured in quads (quadrillion Btu). While energy imports (total quads of oil and natural gas) have been increasing since 1970, the price of energy imports (inflation-adjusted dollar per quad) during that period has also been increasing, meaning that the overall inflation-adjusted dollar value of net energy imports has risen at a much faster rate than the rise in net quad imports. Therefore, not only has the United States been importing more oil and gas to meet its increasing energy consumption, the United States has also been spending significantly more money per unit imported since 1970, further exacerbating the country's trade deficit (earnings from exports minus cost of imports).

As explained below, the United States is now poised to reverse the trend of the last 4 decades and achieve reductions in net energy imports through 2035 due to ongoing declines in U.S. energy intensity and recent developments in U.S. energy production. More stringent fuel economy standards have the potential to further decrease U.S. energy intensity by increasing energy efficiency in the transportation sector (the largest consumer of petroleum and contributor to U.S. net imports).

3.2 Affected Environment

Because energy impacts under the Proposed Action have the potential to affect U.S. energy availability and use, the affected environment for energy encompasses current and projected U.S. energy consumption and production across all fuels and sectors. Section 3.2.1 discusses U.S. energy production and consumption by primary fuel source (petroleum, coal, natural gas, and other); Section 3.2.2 discusses U.S. energy consumption by sector (residential, commercial, industrial, and transportation). Energy data in these two sections are from the 2011 AEO forecast (EIA 2011a[1]), which reflects previously adopted CAFE standards through MY 2016 and assumed MY 2017–2020 fuel economy standards that reflect EISA's requirement that the light duty fleet achieve a combined fuel economy of 35 mpg by MY 2020.[2]

[1] Table 1. Total Energy Supply, Disposition, and Price Summary; Table 2. Energy Consumption by Sector and Source; and Table 17. Renewable Energy Consumption by Sector and Source.
[2] The AEO 2011 forecast does not reflect the impacts of the MY 2014–2018 HD Fuel Efficiency Improvement Program (adopted after the release of AEO 2011) or proposed MY 2017–2025 CAFE standards that exceed the 35

3.2.1 U.S. Production and Consumption of Primary Fuels

Primary fuels are energy sources consumed in the initial production of energy. Energy sources used in the United States include nuclear power, hydropower, coal, natural gas, and crude oil (converted to petroleum and other liquid fuels for consumption), which together account for more than 95 percent of U.S. energy consumption. Other sources, such as biomass and other renewable energy, account for less than 5 percent of U.S. energy consumption.

By 2035, the top five aforementioned energy sources are forecast to account for 92.4 percent of U.S. energy consumption, a reduction of 2.6 percent from their previous share, while the overall share of other fuels is forecast to rise to 7.6 percent (EIA 2011a). Figure 3.2.1-1 illustrates this change in U.S. fuel consumption and production from 2008 to 2035, not including the impacts of the proposed rule or the MY 2014–2018 heavy-duty (HD) vehicle standards. As illustrated in the figure, fuel patterns during the period 2008 to 2035 are anticipated to remain relatively proportionate, with the exception of relative increases in renewable energy.

Although passenger cars and light trucks have the potential to use a number of the different primary fuels currently available in the United States (e.g., biofuels for biofuel vehicles and numerous energy sources with potential for conversion to electricity for electric vehicles), petroleum is overwhelmingly their primary source of energy. As technology and fuel costs and availability change, automotive fuel sources could also change. By requiring increased fuel economy, CAFE standards also have the potential to reduce demand for petroleum in the transportation sector, while potentially increasing the demand for other fuel sources, such as biofuels and fuels used to generate electricity. Understanding how markets for primary fuels will evolve in the coming years is therefore relevant to considerations of the impacts of the Proposed Action.

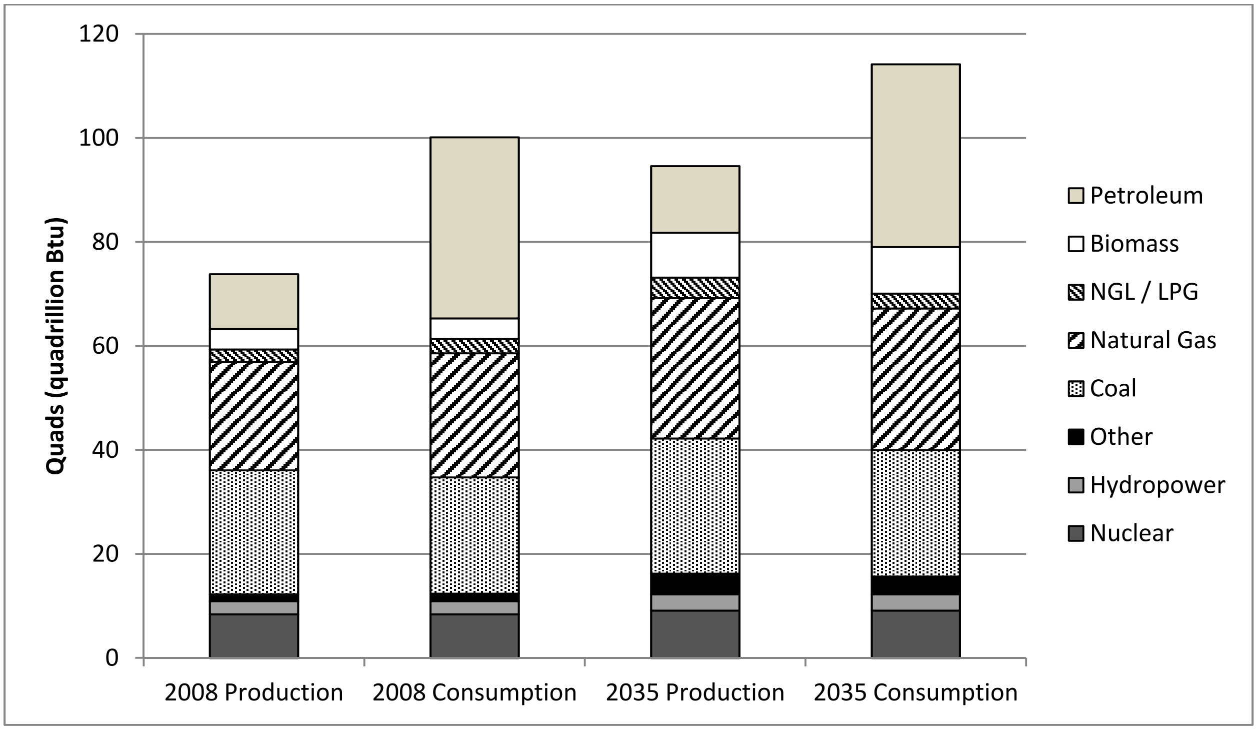
The remainder of this section provides detailed projections for each primary fuel through 2035, including how production and consumption impact net imports or exports of each fuel.

From 2008 to 2035, production and consumption of nuclear power is forecast to increase from 8.4 to 9.1 quads, and production and consumption of hydropower is forecast to increase from 2.5 to 3.1 quads. Because production and consumption values are roughly equivalent for these energy sources, there are virtually no net imports or exports associated with nuclear power or hydropower.[3] Together, these fuels supplied 10.9 percent of total U.S. energy consumption in 2008, and their share of total consumption is forecast to increase to 11.6 percent by 2019 and then fall to 10.7 percent by 2035.

mpg EISA requirement for 2020. The AEO 2011 forecast assumes that CAFE standards are held constant after MY 2020, with forecasted fuel economy improvements after 2020 based on economic cost-benefit analysis from a consumer's and manufacturers' perspective, which does not include energy security and GHG emissions reduction benefits.

[3] There are virtually no U.S. net imports of nuclear power in the sense that U.S. consumption of electricity generated by nuclear power is supplied by U.S. nuclear power plants. Supply and consumption of nuclear fuel at different stages of processing is more complex, with new U.S. supply sources expected to reduce U.S. dependence on nuclear fuel imports by 2020. The nuclear fuel cycle includes the mining of uranium ore, conversion into uranium hexafluoride, and enrichment to increase the concentration of uranium-235 in uranium hexafluoride (USNRC 2011). The United States produced only 5 percent of the uranium consumed by U.S. nuclear plants in 2003, relying on substantial imports from Canada and Australia, but ranks sixth in the world for known uranium resources, and there has been a significant increase in exploration and plans to reopen old mines as the price of uranium has increased in recent years. There are also significant expansions planned for U.S. conversion capacity to produce uranium hexafluoride, and a substantial increase in U.S. enrichment capacity is expected from three new enrichment plants likely to begin operation before 2020 (USNRC 2011).

Figure 3.2.1-1. U.S. Energy Production and Consumption by Source in 2008 and 2035[a,b] (excluding impacts of MY 2014–2018 HD Vehicle Standards and MY 2017–2025 CAFE Standards)



a. Source: EIA 2011a, Table 1. Total Energy Supply, Disposition, and Price Summary; Table 2. Energy Consumption by Sector and Source; and Table 17. Renewable Energy Consumption by Sector and Source.
b. Btu = British thermal units; NGL = natural gas liquid; LPG = liquefied petroleum gas.

Both production and consumption of coal fell from 2008 to 2009 during the recession, but are expected to surpass 2008 levels by 2015. U.S. coal production is forecast to increase from 23.8 quads in 2008 to 26.0 quads in 2035. Coal consumption is expected to rise from 22.4 quads in 2008 to 24.3 quads in 2035. The United States is currently, and is expected to remain, a net exporter of coal energy through 2035, because the country is anticipated to continue to produce slightly more coal than it consumes.

U.S. production of dry natural gas (separated from natural gas liquids, discussed below) is forecast to increase from 20.8 quads in 2008 to 27.0 quads in 2035. This forecast growth is due to new production technologies that can extract U.S. shale gas, a specific form of natural gas that has previously been too difficult to utilize commercially. U.S. shale gas production specifically is expected to rise more than fivefold between 2007 and 2035, more than offsetting an expected decline in conventional natural gas production. U.S. consumption of natural gas is expected to rise at a slower rate than its production – from 23.8 quads in 2008 to 27.2 quads in 2035 – thereby making U.S. anticipated net imports of natural gas fall to near zero by 2035.

Production of natural gas liquid (a similar but heavier hydrocarbon compared to dry natural gas) is forecast to increase from 2.4 quads in 2008 to 3.9 quads in 2035. After extraction, natural gas liquid is separated from dry natural gas in processing plants, and sold as ethane, propane, and other liquefied petroleum gases for consumption. Consumption of liquefied petroleum gas is forecast to increase from 2.77 quads in 2008 to 2.84 quads in 2035. Therefore, the increase in natural gas liquid production is expected to outpace the increase in liquefied petroleum gas consumption, resulting in marginal net exports by 2035 for this subset of liquid fuels.

U.S. production of biomass energy (e.g., grid-connected electricity from wood and wood waste; liquid fuels production from crops; and direct (non-electric) energy from wood) is forecast to increase from 3.9 quads in 2008 to 8.63 quads in 2035. Biomass energy consumption is forecast to rise even faster, from 3.9 quads in 2008 to 8.98 quads in 2035. Excess energy consumption in 2035 is anticipated to be met by importing 0.33 quads of ethanol. Projected growth in biomass energy use is mostly due to a forecast increase in ethanol, biodiesel, and other biomass liquids used in transportation, from 0.9 quads in 2008 to 3.7 quads in 2035.

U.S. production of crude oil is forecast to increase from 10.5 quads in 2008 to 12.8 quads in 2035. Crude oil is refined into petroleum (including liquid fuel such as gasoline and diesel, but not including non-petroleum liquid fuels, such as biofuels and liquefied petroleum gas) for consumption. U.S. consumption of petroleum is forecast to increase from 34.8 quads in 2008 to 35.1 quads in 2035. Therefore, U.S. net imports of petroleum are forecast to decline slightly from approximately 24 quads in 2008 to 22 quads in 2035. Reductions in net petroleum imports are anticipated to result from ongoing declines in energy intensity as discussed in Section 3.1 (as stated, these figures do not include the impacts of the MY 2014–2018 HD vehicle standards or the proposed MY 2017–2025 CAFE standards, which would contribute to additional declines in petroleum imports).

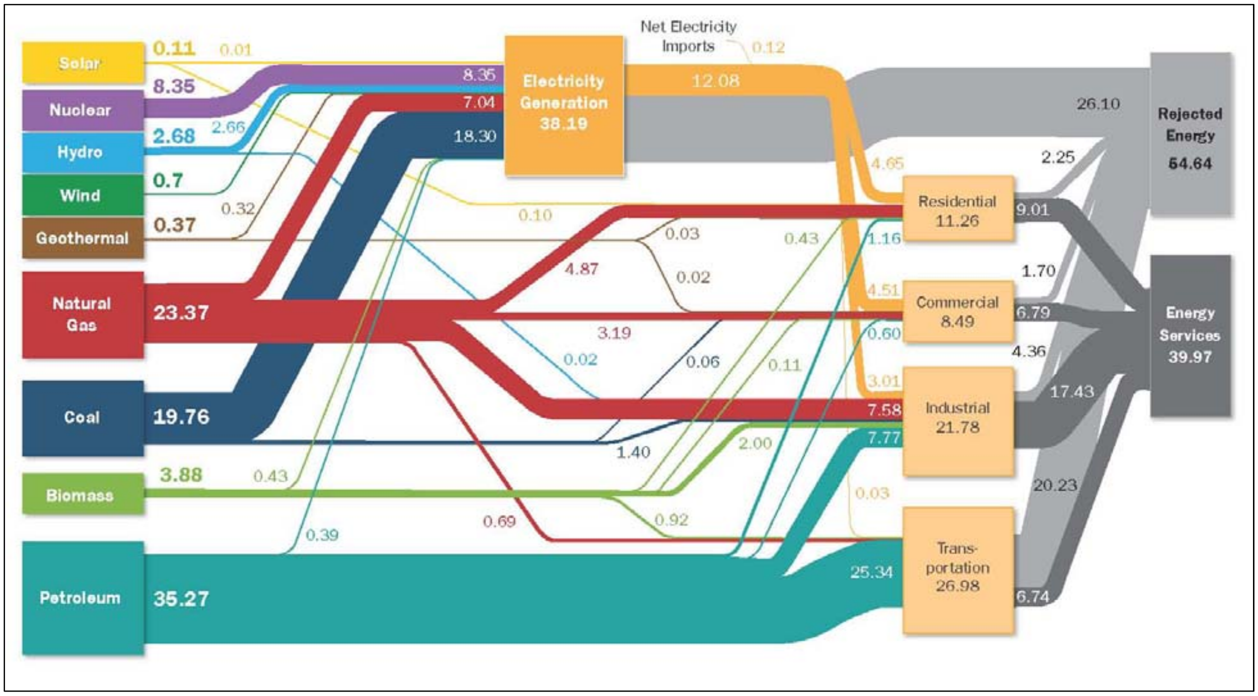
The primary fuel projections discussed above demonstrate that there are likely to be essentially no U.S. net imports of nuclear power, hydropower, natural gas, and biomass and other renewable energy, and minor U.S. net exports of coal and natural gas liquid and liquefied petroleum gas by 2035. However, petroleum will continue to require significant net imports to meet consumption demands. Despite modest reductions in net petroleum imports by 2035, petroleum imports will continue to be magnitudes greater than net energy exports, resulting in a continued U.S. trade deficit from the energy sector.

3.2.2 U.S. Energy Consumption by Sector

While Section 3.2.1 describes overall U.S. production and consumption of primary fuels, this section discusses the usage of primary fuels by sector. Energy consumption occurs in four broad economic sectors: industrial, residential, commercial, and transportation. These sectors can be categorized as either stationary (including industrial, residential, and commercial sectors) or mobile (i.e., transportation). Stationary and transportation sectors consume primary fuels as described above (e.g., nuclear, coal, and petroleum), and electricity. Electric power generation consumes primary fuel to provide electricity to the industrial, residential, commercial, and transportation sectors. This section describes how different fuels, including electricity, are more or less conducive to use in the different sectors. Consequently, regulations by sector will have different implications for specific fuel usage and overall impacts to the U.S. economy.

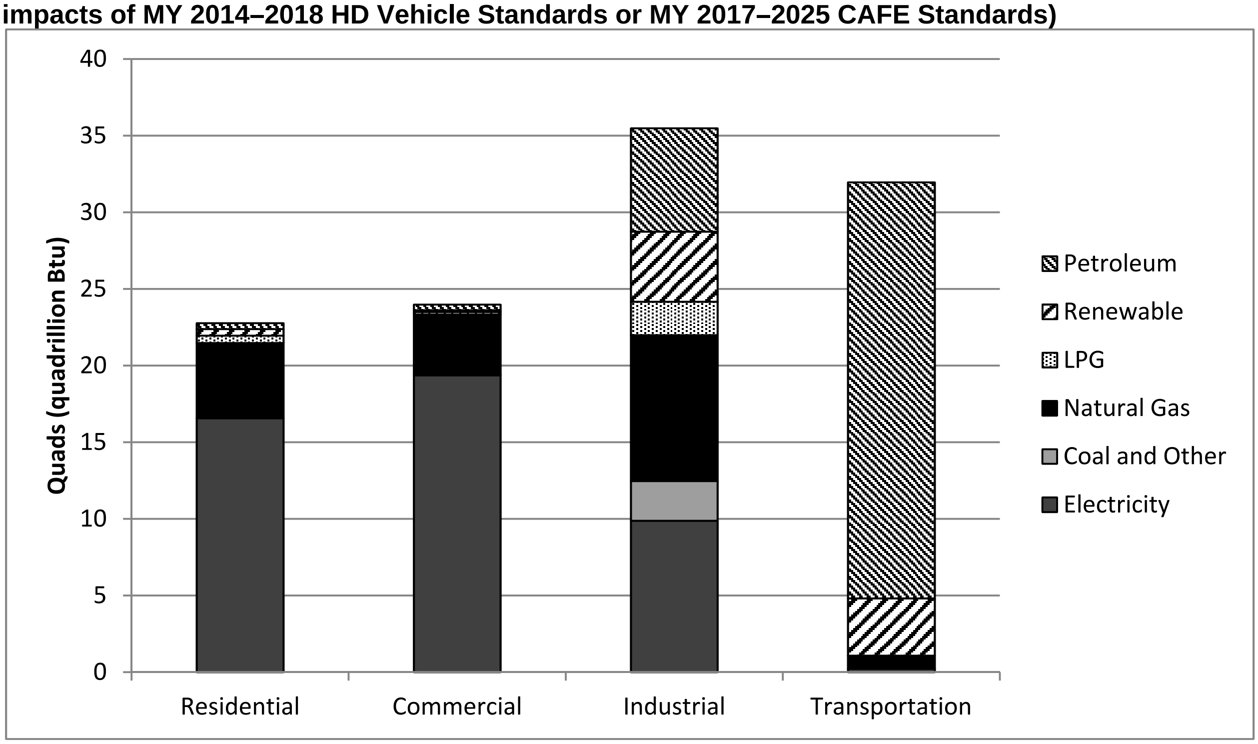
Figure 3.2.2-1 shows the relative amounts of energy produced from each energy source and consumed by each sector in 2009; Figure 3.2.2-2 illustrates the different fuel uses for each sector as projected through 2035. As shown in these figures, stationary and transportation sectors use a sharply contrasting profile of fuels, with stationary sources consuming more electricity and natural gas, and the transportation sector consuming primarily petroleum. Sections 3.2.2.1 and 3.2.2.2 discuss the specifics of fuel use by stationary and transportation sectors, respectively.

Figure 3.2.2-1. U.S. Energy Flows[a,b,c]



a. Source: DOE 2011d citing LLNL 2009.
b. Values are in quadrillion Btu; total energy is approximately 95 quads.
c. *Rejected energy* is energy lost as waste heat throughout the generation and transmission process. Most of these losses occur when energy is converted from one form to another. *Energy services* refers to the energy successfully transmitted to its end designation.

Figure 3.2.2-2. U.S. Energy Consumption by End-Use Sector and Source Fuel in 2035[a,b] (excluding impacts of MY 2014–2018 HD Vehicle Standards or MY 2017–2025 CAFE Standards)



a. Source: EIA 2011a, Table 2. Energy Consumption by Sector and Source; and Table 17. Renewable Energy Consumption by Sector and Source.
b. Btu = British thermal units; LPG = liquefied petroleum gas.

3.2.2.1 Stationary Sector Fuel Consumption

Electricity and heat (produced on site from natural gas) are the principal forms of energy used by the residential and commercial sectors, accounting for well over 90 percent of their own energy use and approximately 40 percent of total U.S. primary energy consumption. The industrial sector has more diverse energy consumption patterns, including electricity, natural gas, and renewable energy. This sector consumes another 30 percent of the nation's total energy. New energy technologies to supply stationary energy to consumers must compete with an existing infrastructure that delivers these fuels reliably and at a low cost.

Residential sector energy consumption is forecast to rise from 21.5 quads in 2008 to 22.8 quads in 2035. In 2008, electricity (including energy lost during generation and transmission, when one form of energy is converted to another, referred to herein as "losses") supplied 69 percent of residential demand and natural gas (not converted to electricity) supplied 23 percent. In 2035, electricity is expected to supply 73 percent and natural gas 22 percent. The liquefied petroleum gas share is forecast to decline from 2.4 percent in 2008 to 2.1 percent in 2035, and the renewable energy (e.g., wood and solar) share is expected to decline from 2.1 percent in 2008 to 1.8 percent in 2035. The fuel oil share of residential energy is also expected to decline from 3.1 percent in 2008 to 1.6 percent in 2035.

Commercial sector energy consumption is forecast to rise from 18.4 quads in 2008 to 24.0 quads in 2035. In 2008, electricity (including losses) supplied 79 percent of commercial energy demand, and natural gas supplied 17 percent. In 2035, electricity is expected to supply 81 percent and natural gas 16 percent. The liquid fuel share of commercial energy, including liquefied petroleum gas and petroleum, is expected to decline from 3.5 percent in 2008 to 2.2 percent in 2035.

Industrial sector energy consumption is projected to rise from 32.2 quads in 2008 to 35.5 quads in 2035. In 2008, electricity (including losses) supplied 34 percent of industrial demand, coal supplied 5 percent, natural gas 21 percent, and biofuels, their co-products (including other products produced as by-products during ethanol fuel and biodiesel production), and other renewable energy 8 percent. In 2035, electricity (including losses) is expected to supply 28 percent of industrial energy use, with coal supplying 7 percent, natural gas 27 percent, and biofuels, their co-products, and renewable energy supplying 13 percent. The liquid fuel share of industrial energy use is anticipated to decline from 28 percent in 2008 to 25 percent in 2035, with liquefied petroleum gas supplying approximately one-fourth of this industrial liquid fuel demand.

Total energy consumption from electric power, which feeds into all stationary sector activities (as described in this section) and some transportation activities (as described in Section 3.2.2.2), is forecast to rise from 40.2 quads in 2008 to 46.0 quads in 2035. In 2008, nuclear power supplied 17 percent of electric power generation source fuel, coal 51 percent, natural gas 21 percent, and hydropower and other renewable energy 9 percent. In 2035, nuclear power is predicted to supply 18 percent, coal 47 percent, natural gas 20 percent, and hydropower and other renewable energy 14 percent. The petroleum share of electric power fuel supply is anticipated to decline from 1.2 percent in 2008 to 1.0 percent in 2035.

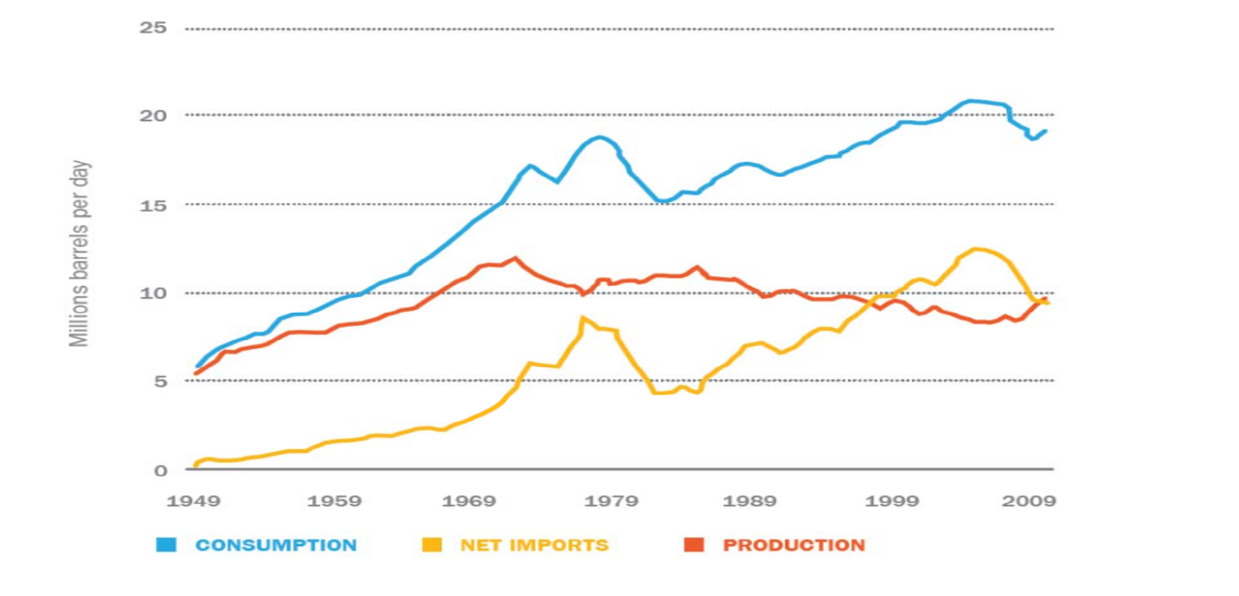
3.2.2.2 Transportation Sector Fuel Consumption

Transportation energy consumption is forecast to rise from 28 quads in 2008 to 32 quads in 2035. In 2008, petroleum and other liquid fuel supplied 97.3 percent of transportation energy demand, and natural gas supplied 2.5 percent. In 2035, petroleum and other liquid fuel are expected to supply 96.7 percent, and natural gas 2.6 percent. The biofuel share of transportation liquid fuel is projected to rise from 3.2 percent in 2008 to 12.1 percent in 2035. Liquefied petroleum gas accounts for less than 0.1 percent of liquid fuel consumption in the transportation sector.

Almost 95 percent of U.S. transportation sector energy comes from petroleum, nearly half of which is imported. In 2035, jet fuel is forecast to account for 13 percent of transportation sector petroleum consumption, and heavy-duty trucks and light-duty vehicles are forecast to account for 87 percent. With petroleum expected to account for the vast majority of all energy imports, and transportation expected to account for 77.3 percent of petroleum consumption in 2035, U.S. net energy imports in 2035 are forecast to result primarily from fuel consumption by heavy-duty trucks and light-duty vehicles. Negligible U.S. net energy imports in 2035 are anticipated to be related to the residential or commercial sectors because petroleum accounts for only a very small fraction of source fuel used in these sectors, and because the fuels that are used in these sectors account for a very small fraction of energy imports.

As shown in Figure 3.2.2-3, the net import fraction of petroleum and other liquid fuels has dropped from more than 60 percent in 2005 to 50 percent in 2010. As reported by DOE (2011d), the net import fraction of petroleum and other liquid fuels is expected to drop to 42 percent in 2035, due to a combination of more stringent vehicle fuel economy standards and increased domestic production of both crude oil and biofuels. (This 2035 forecast does not include the impacts of MY 2014–2018 HD vehicle standards and MY 2017–2025 CAFE standards.) In absolute terms, the volume of imports for the United States is projected to be effectively constant through 2035.

Figure 3.2.2-3. Consumption, Production, and Net Imports of Petroleum and Other Liquid Fuels, 1949–2009[a]



a. Source: DOE 2011d citing EIA 2011.

Section 3.3 discusses potential impacts of the Proposed Action on fuel consumption and fuel savings through 2050. As demonstrated by the current and projected statistics described in this section, the affected environment of energy consumption and production in the United States strongly suggests a potential for reduced petroleum consumption and, correspondingly, a reduction in net imports and the trade deficit through increased vehicle efficiency in the transportation sector.

3.3 Environmental Consequences

Section 3.3.1 examines the direct and indirect impact on fuel consumption associated with the action alternatives under Analysis A and Analysis B. Section 3.3.2 examines the effects on fuel consumption under the cumulative impacts analysis. As explained in Chapter 2:

- Analysis A measures the impact of action alternatives where fleetwide fuel economy after MY 2025 will never exceed the level of the MY 2025 standards, in relation to a No Action Alternative under which the fleet would attain an average fleetwide fuel economy no higher than that required under the agencies' MY 2016 standards established by final rule in April 2010. Tables and figures in this chapter that depict results for Analysis A include an "A" after the table or figure number.
- Analysis B measures the impact of action alternatives assuming ongoing increases beyond the level of the MY 2025 standards in new vehicle fuel economy after MY 2025, in relation to a No Action Alternative that assumes the average fleetwide fuel economy level of light-duty vehicles would continue to increase beyond the level necessary to meet the MY 2016 standards, even in the absence of agency action. Tables and figures in this chapter that depict results for Analysis B include a "B" after the table or figure number.
- The cumulative impacts analysis measures the impact of fuel economy improvements that result directly or indirectly from the proposed rule in addition to reasonably foreseeable improvements in fuel economy caused by other actions – that is, fuel economy improvements that would result from actions taken by manufacturers without the agency's action.

3.3.1 Direct and Indirect Impacts

Table 3.3.1-1-A lists combined direct and indirect fuel consumption under Analysis A for each alternative for 2017–2060, when essentially the entire light-duty vehicle fleet will be composed of MY 2025 or later vehicles. Table 3.3.1-1-B lists combined direct and indirect fuel consumption for Analysis B. Both tables report total 2017–2060 consumption of gasoline gallon equivalents, including gasoline, diesel, biofuel, and electricity. The tables list results for cars, light trucks, and for all light-duty vehicles. These tables also show total 2017–2060 fuel savings resulting from each action alternative compared to the No Action Alternative.

Table 3.3.1-1-A. Fuel Consumption and Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Analysis A

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Fuel Consumption				
Cars	3,347	3,021	2,750	2,404
Light trucks	3,746	3,340	3,110	2,811
All light-duty vehicles	7,092	6,361	5,860	5,216
Fuel Savings Compared to the No Action Alternative				
Cars		326	597	942
Light trucks		406	635	934
All light-duty vehicles		731	1,232	1,877

Table 3.3.1-1-B. Fuel Consumption and Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Analysis B

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Fuel Consumption				
Cars	3,061	2,782	2,564	2,220
Light trucks	3,360	3,194	3,019	2,744
All light-duty vehicles	6,421	5,975	5,583	4,964
Fuel Savings Compared to the No Action Alternative				
Cars		280	497	841
Light trucks		166	341	616
All light-duty vehicles		446	838	1,457

Figures 3.3.1-2-A and 3.3.1-2-B show fuel savings for cars and light trucks by alternative for Analyses A and B.Under Analysis A, light-duty vehicle fuel consumption from 2017–2060 under the No Action Alternative is projected to be 7,092 billion gallons. Total 2017–2060 fuel consumption is projected to be 6,361 billion gallons under Alternative 2, 5,860 billion gallons under the Preferred Alternative, and 5,216 billion gallons under Alternative 4. Compared to the No Action Alternative, total 2017–2060 fuel savings would range from 731 billion gallons under Alternative 2 to 1,877 gallons under Alternative 4, with 1,232 billion gallons saved under the Preferred Alternative.

Under Analysis B, light-duty vehicle fuel consumption from 2017–2060 under the No Action Alternative is projected to be 6,421 billion gallons. Total 2017–2060 fuel consumption is projected to be 5,975 billion gallons under Alternative 2, 5,583 under the Preferred Alternative, and 4,964 billion gallons under Alternative 4. Compared to the No Action Alternative, total 2017–2060 fuel savings would range from 446 billion gallons under Alternative 2 to 1,457 billion gallons under Alternative 4, with 838 billion gallons saved under the Preferred Alternative.

Figure 3.3.1-2-A. U.S. Passenger Car and Light Truck Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Analysis A

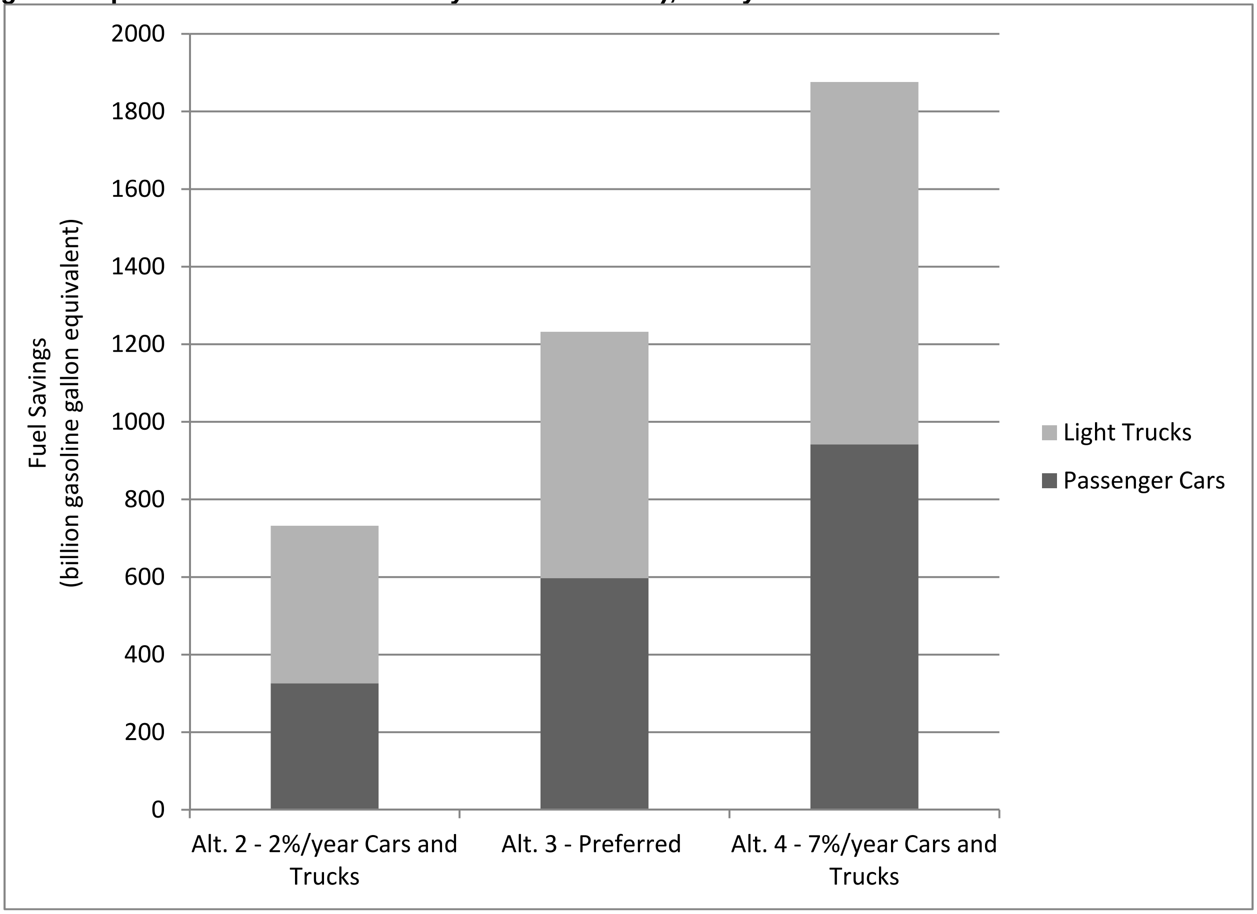
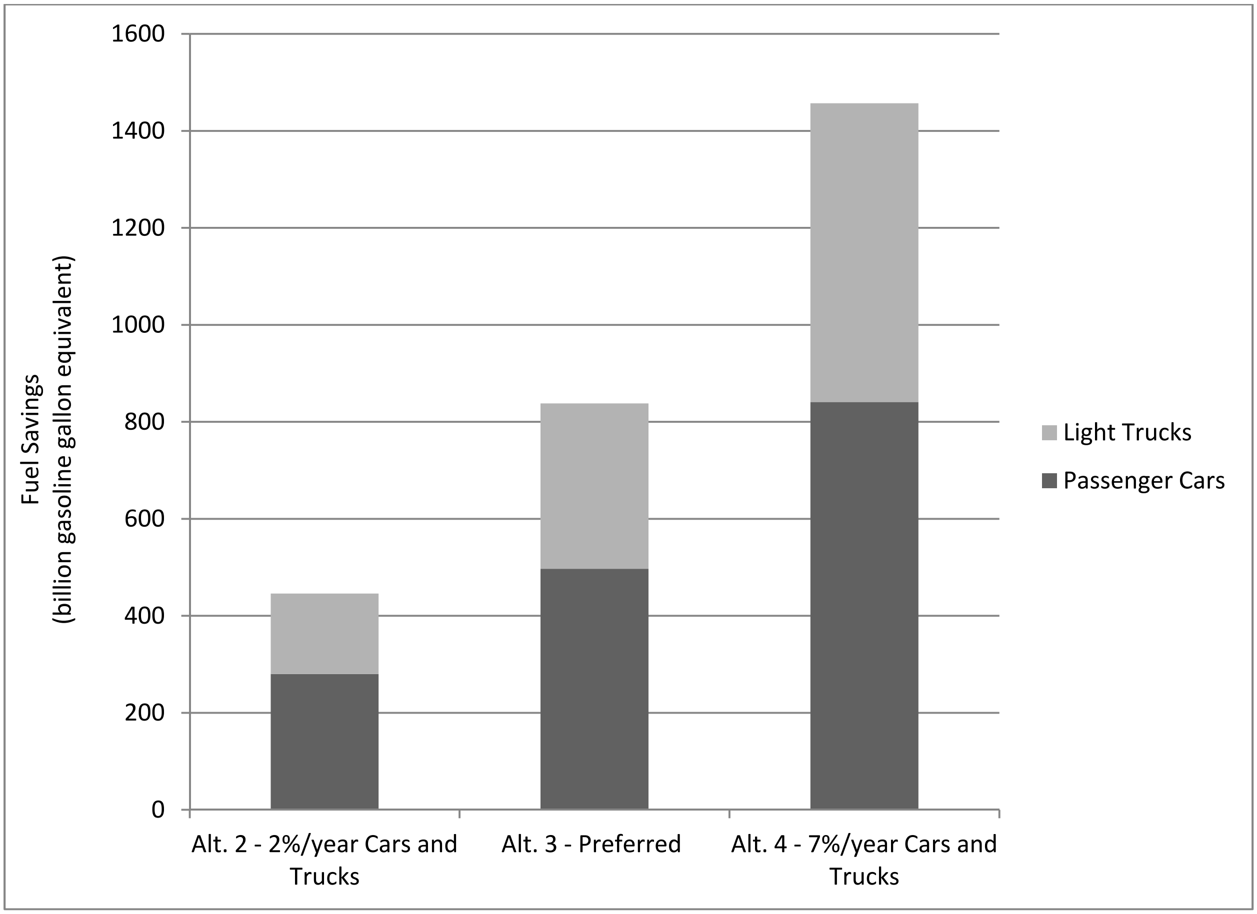


Figure 3.3.1-2-B. U.S. Passenger Car and Light Truck Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Analysis B



3.3.2 Cumulative Impacts

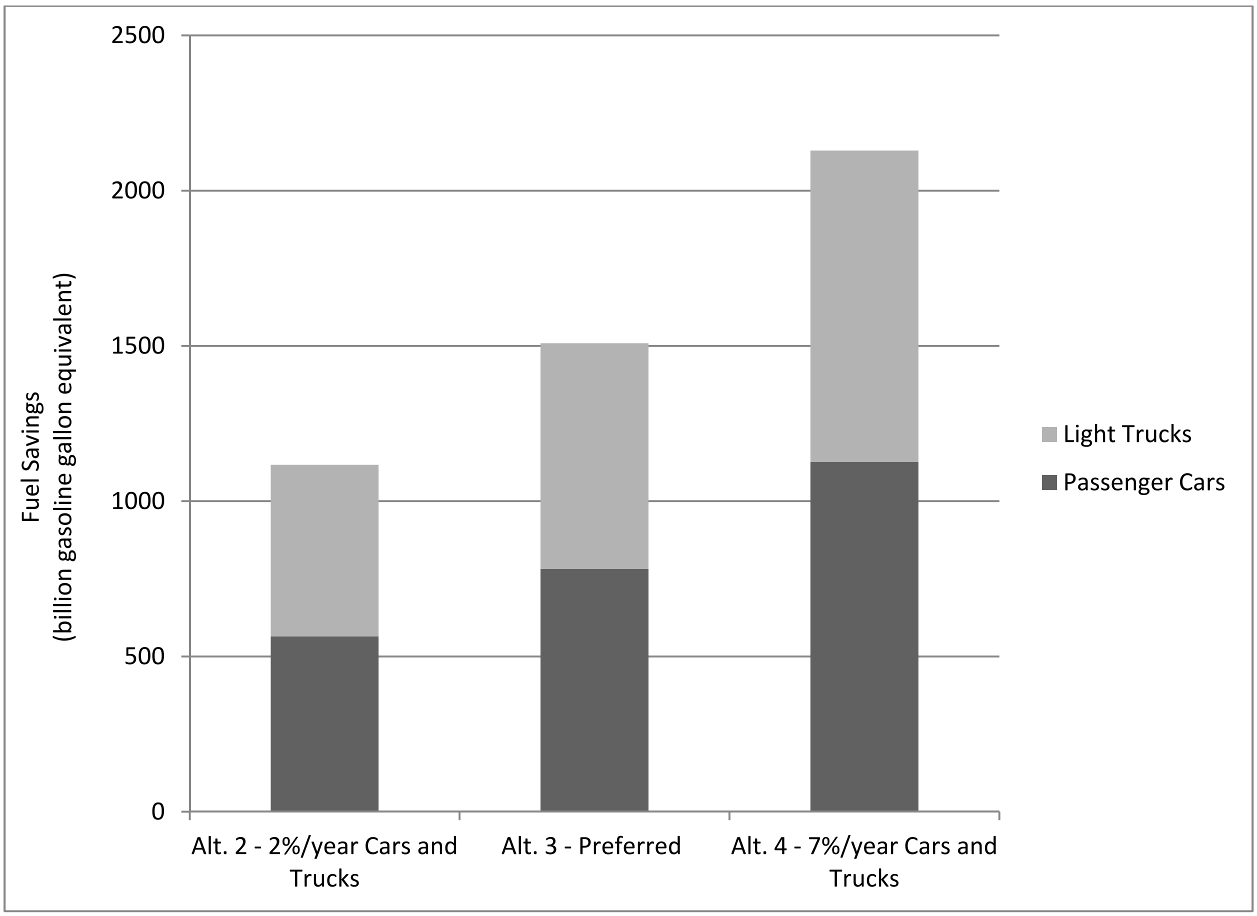
Table 3.3.2-1 lists the total fuel consumption and savings for each alternative for 2017–2060 under the cumulative impacts analysis. Values are reported in gasoline gallon equivalents, including gasoline, diesel, biofuel, and electricity. Separate results are shown for cars, light trucks, and for all light-duty vehicles. Figure 3.3.2-1 shows the fuel savings under the cumulative impacts analysis for each action alternative for cars and light trucks compared to the No Action Alternative.

Under the cumulative impacts analysis, light-duty vehicle fuel consumption for years 2017–2060 under the No Action Alternative is projected to be 7,092 billion gallons. Total 2017–2060 fuel consumption for the cumulative impacts analysis is 5,975 billion gallons under Alternative 2, 5,583 under the Preferred Alternative, and 4,964 billion gallons under Alternative 4. Compared to the No Action Alternative, the cumulative impacts analysis projects total 2017–2060 fuel savings ranging from 1,117 billion gallons under Alternative 2 to 2,128 billion gallons under Alternative 4, with 1,509 billion gallons saved under the Preferred Alternative.

Table 3.3.2-1. Fuel Consumption and Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Cumulative Impacts Analysis

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Fuel Consumption				
Cars	3,347	2,782	2,564	2,220
Light trucks	3,746	3,194	3,019	2,744
All light-duty vehicles	7,092	5,975	5,583	4,964
Fuel Savings Compared to No Action Alternative				
Cars		565	782	1,127
Light trucks		552	727	1,002
All light-duty vehicles		1,117	1,509	2,128

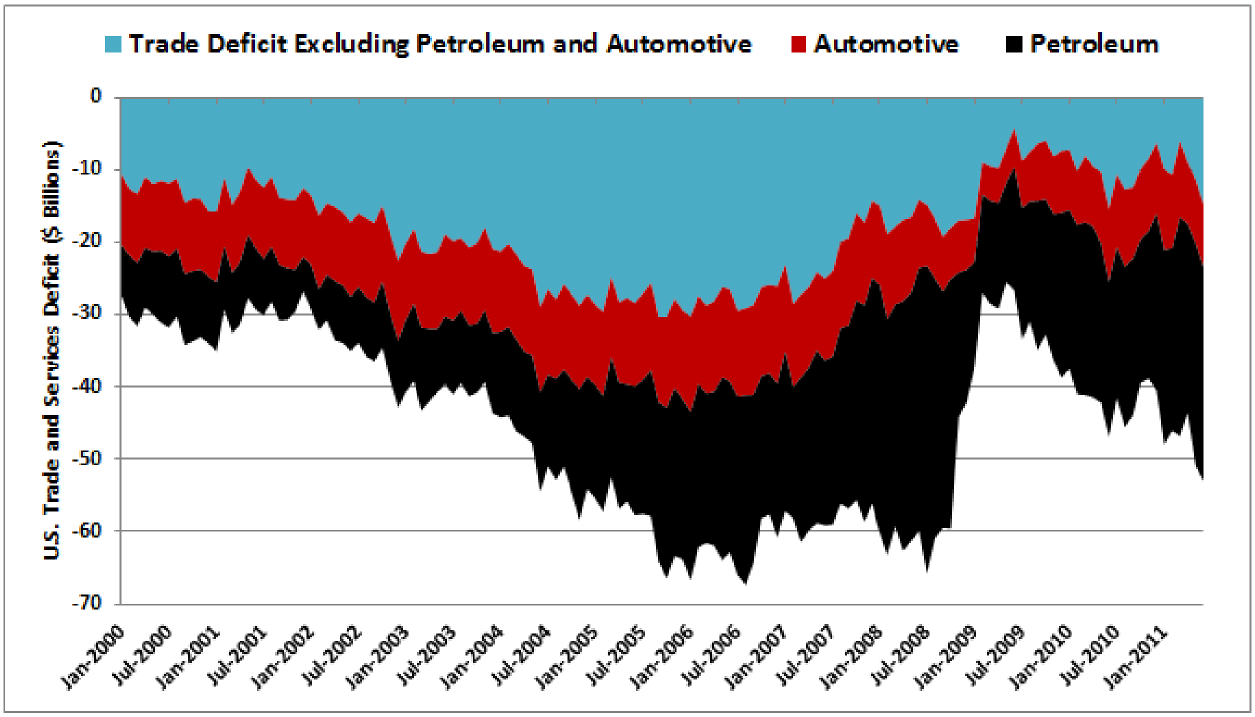
Figure 3.3.2-1. U.S. Passenger Car and Light Truck Fuel Savings by Alternative (billion gasoline gallon equivalent total for calendar years 2017–2060), Cumulative Impacts



The fuel savings under the Preferred Alternative, when considered together with the impact of MY 2014–2018 HD vehicle standards and other related public and private investments in transportation fuel efficiency, should result in U.S. net energy imports in 2035 that are substantially below the AEO forecast shown in Figure 3.2.2-2. Moreover, this reduction in net energy imports could reduce the total U.S. trade deficit in goods and services.

As noted above, the AEO forecast for U.S. energy supply and demand, shown in Figure 3.2.2-2, reflects previously enacted CAFE standards through MY 2016 and assumed MY 2017–2020 fuel economy standards that reflect EISA's requirement that the light-duty fleet achieve a combined fuel economy of 35 mpg by MY 2020. It does not reflect the impacts of the MY 2014–2018 HD vehicle standards or the proposed MY 2017–2025 CAFE standards. In 2035, the combined impact of the Preferred Alternative for MY 2017–2025 CAFE standards and the MY 2014–2018 HD vehicle standards would reduce petroleum consumption in transportation by more than 14 percent below the 2035 petroleum consumption forecast shown in Figure 3.2.2-2, and reduce forecast 2035 U.S. net imports of petroleum by more than 22 percent.

Figure 3.3.2-2. U.S. Trade Deficit in Goods and Services 2000–2011[a]



a. Source: U.S. Census Bureau 2011.

The proposed MY 2017–2025 CAFE standards build on substantial public and private investments over the past 2 years to transition to more fuel-efficient light-duty vehicles, parts, and engines manufactured in the United States. The American Recovery and Reinvestment Act of 2009 (Pub. L. 111-5) included $2.4 billion to establish 30 electric vehicle battery and component manufacturing plants, and there has been an equal or greater private-sector investment in these plants. In 2009, the U.S. produced less than 2 percent of the world's advanced vehicle batteries, but is now expected to have capacity to produce 20 percent of global advanced vehicle batteries by 2012, and 40 percent by 2015 (DOE 2010). This investment established a foundation to support other investments in automotive manufacturing and technology, and will help to achieve substantial MY 2017–2025 gains in U.S. light-duty vehicle fuel economy.

Figure 3.3.2-2 illustrates that petroleum net imports, primarily for fueling HD trucks and light-duty vehicles, plus net imports of motor vehicles and motor vehicle parts and engines, accounted for 76 percent of the total U.S. trade deficit in goods and services from January 2009 through June 2011 (U.S. Census Bureau 2011). The other 24 percent of the overall trade deficit reflects the U.S. surplus in services trade that is more than offset by the U.S. trade deficit in all goods other than petroleum and motor vehicles, parts, and engines. Recent spikes in oil prices, such as the 2005–2008 oil price hikes, have also caused large increases in the petroleum share of the trade deficit in dollars, as seen in Figure 3.3.2-2, despite the fact that net petroleum quad imports were comparatively stable during this time. Therefore, a broader perspective on the cumulative impacts of the proposed MY 2017–2025 CAFE standards, in addition to the impacts of the MY 2014–2018 HD vehicle standards and other related investments in transportation fuel efficiency, indicates that these actions also could reduce the total U.S. trade deficit in goods and services.

CHAPTER 4 AIR QUALITY

4.1 Affected Environment

4.1.1 Relevant Pollutants and Standards

The proposed standards would affect air pollutant emissions and air quality, which in turn would affect public health and welfare, as well as the natural environment. Many human activities cause gases and particles to be emitted into the atmosphere. These activities include driving cars and trucks; burning coal, oil, and other fossil fuels; manufacturing chemicals and other products; and smaller, everyday activities such as dry cleaning, degreasing, and painting operations, and the use of consumer products. When these gases and particles accumulate in the air in high enough concentrations, they can harm humans, especially children, the elderly, the ill, and other sensitive individuals, and can damage crops, vegetation, buildings, and other property. Many air pollutants remain in the environment for long periods and are carried by the wind hundreds of miles from their origin. People exposed to high enough levels of certain air pollutants can experience burning in their eyes, an irritated throat, breathing difficulties, or other respiratory symptoms. Long-term exposure to air pollution can cause cancer, hospitalization for heart or lung diseases, and long-term damage to the immune, neurological, reproductive, and respiratory systems. In extreme cases, it can even cause death (EPA 2011b).

To reduce air pollution levels, the Federal Government and state agencies have passed legislation and established regulatory programs to control sources of emissions. The Clean Air Act (CAA) is the primary federal legislation that addresses air quality. Under the CAA, as amended, EPA has established National Ambient Air Quality Standards (NAAQS) for six criteria pollutants (relatively commonplace pollutants that can accumulate in the atmosphere as a result of normal levels of human activity).[1] This air quality analysis assesses the impacts of the No Action Alternative and action alternatives in relation to these criteria pollutants. It also assesses how the alternatives are projected to impact the emissions of certain hazardous air pollutants.

The criteria pollutants analyzed in this EIS include: carbon monoxide (CO), nitrogen dioxide (NO_2) (one of several oxides of nitrogen), ozone, sulfur dioxide (SO_2), particulate matter (PM) with a nominal aerodynamic diameter equal to or less than 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$, or fine particles), and lead. Ozone is not emitted directly from vehicles, but is evaluated based on emissions of the ozone precursor pollutants nitrogen oxides (NO_x) and volatile organic compounds (VOCs).

Total emissions from on-road mobile sources have declined dramatically since 1970 as a result of pollution controls on vehicles and regulation of the chemical content of fuels, despite continuing increases in the amount of vehicle travel. From 1970 to 2011, emissions from on-road mobile sources declined 80 percent for CO, 70 percent for NO_x, 80 percent for PM_{10}, 88 percent for SO_2, and 83 percent for VOCs. Emissions of $PM_{2.5}$ from on-road mobile sources declined 75 percent from 1990, the earliest year for which data are available, to 2011 (EPA 2011c).

[1] "Criteria pollutants" is a term used to collectively describe the six common air pollutants for which the CAA requires EPA to set NAAQS. EPA calls these pollutants "criteria" air pollutants because it regulates them by developing human-health based or environmentally based criteria (science-based guidelines) for setting permissible levels. "Hazardous air pollutants," by contrast, refers to substances defined as hazardous by the 1990 CAA amendments. These substances include certain VOCs, compounds in PM, pesticides, herbicides, and radionuclides that present tangible hazards, based on scientific studies of human (and other mammal) exposure.

Nevertheless, the U.S. transportation sector remains a major source of emissions of certain criteria pollutants or their chemical precursors. On-road mobile sources (highway vehicles) are responsible for 33,100,000 tons per year of CO (53 percent of total U.S. emissions), 80,600 tons per year (1.7 percent) of $PM_{2.5}$ emissions, and 94,500 tons per year (1.2 percent) of PM_{10} emissions (EPA 2009a). Almost all of the PM in motor vehicle exhaust is $PM_{2.5}$ (Gertler et al. 2000); therefore, this analysis focuses on $PM_{2.5}$ rather than PM_{10}. On-road mobile sources also contribute 2,940,000 tons per year (24 percent of total nationwide emissions) of VOCs and 3,760,000 tons per year (31 percent) of NO_x emissions, which are chemical precursors of ozone. In addition, NO_x is a $PM_{2.5}$ precursor and VOCs can be $PM_{2.5}$ precursors.[2] SO_2 and other oxides of sulfur (SO_x) are important because they contribute to the formation of $PM_{2.5}$ in the atmosphere; however, on-road mobile sources account for less than 0.39 percent of U.S. SO_2 emissions. With the elimination of lead in automotive gasoline, lead is no longer emitted from motor vehicles in more than negligible quantities. Lead is therefore not addressed in this analysis.

Table 4.1.1-1 lists the primary and secondary NAAQS for each criteria pollutant. Under the CAA, EPA sets primary standards at levels intended to protect against adverse effects on human health; secondary standards are intended to protect against adverse effects on public welfare, such as damage to agricultural crops or vegetation and damage to buildings or other property. Because each criteria pollutant has different potential effects on human health and public welfare, the NAAQS specify different permissible levels for each pollutant. NAAQS for some pollutants include standards for short- and long-term average levels. Short-term standards are intended to protect against acute health effects from short-term exposure to higher levels of a pollutant; long-term standards are established to protect against chronic health effects resulting from long-term exposure to lower levels of a pollutant.

Table 4.1.1-1. National Ambient Air Quality Standards[a]

Pollutant	Primary Standards		Secondary Standards	
	Level[b]	Averaging Time	Level[b]	Averaging Time
Carbon monoxide	9 ppm (10 mg/m^3)	8 hours[c]	None	
	35 ppm (40 mg/m^3)	1 hour[c]		
Lead	0.15 $\mu g/m^3$	Rolling 3-month average	Same as Primary	
Nitrogen dioxide	0.053 ppm (100 $\mu g/m^3$)	Annual (arithmetic mean)	Same as Primary	
	0.100 ppm (200 $\mu g/m^3$)	1 hour[d]	None	
Particulate matter (PM_{10})	150 $\mu g/m^3$	24 hours[e]	Same as Primary	
Particulate matter ($PM_{2.5}$)	15.0 $\mu g/m^3$	Annual (arithmetic mean)[f]	Same as Primary	
	35 $\mu g/m^3$	24 hours[g]	Same as Primary	

[2] NO_x can undergo chemical transformations in the atmosphere to form nitrates. VOCs can undergo chemical transformations in the atmosphere to form other various carbon compounds. Nitrates and carbon compounds can be major constituents of $PM_{2.5}$. Highway vehicle emissions are large contributors to nitrate formation nationally (EPA 2004a).

Table 4.1.1-1. National Ambient Air Quality Standards[a] (continued)

Pollutant	Primary Standards		Secondary Standards	
	Level[b]	Averaging Time	Level[b]	Averaging Time
Ozone	0.075 ppm	8 hours[h]	Same as Primary	
Sulfur dioxide	0.075 ppm (200 μg/m^3)	1 hour[i]	0.5 ppm (1,300 μg/m^3)	3 hours[c]

a. Source: 40 CFR Part 50, as presented in EPA 2011d.
b. Units of measure for the standards are parts per million (ppm) by volume, milligrams per cubic meter of air (mg/m^3), and micrograms per cubic meter (μg/m^3) of air.
c. Not to be exceeded more than once per year.
d. To attain this standard, the 3-year average of the 98th percentile of the daily maximum 1-hour average at each monitor within an area must not exceed 0.100 ppm (effective January 22, 2010).
e. Not to be exceeded more than once per year on average over 3 years.
f. To attain this standard, the 3-year average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15.0 μg/m^3.
g. To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 35 μg/m^3 (effective December 17, 2006).
h. To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor in an area over each year must not exceed 0.075 ppm (effective May 27, 2008).
i. The 1-hour sulfur dioxide standard is attained when the 3-year average of the 99th percentile of the daily maximum 1-hour average concentrations does not exceed 0.075 ppm.

NAAQS are most commonly used to help assess the air quality of a geographic region by comparing the levels of criteria air pollutants found in the atmosphere to the levels established by NAAQS. Concentrations of criteria pollutants in the air mass of a region are measured in parts of a pollutant per million parts of air (ppm) or in micrograms of a pollutant per cubic meter of air (μg/m^3) present in repeated air samples taken at designated monitoring locations. These ambient concentrations of each criteria pollutant are compared to the permissible levels specified by NAAQS to assess whether the region's air quality could be unhealthful.

Under the CAA, EPA is required to review NAAQS every 5 years and to change the levels of the standards if warranted by new scientific information. The NAAQS formerly included an annual PM_{10} standard, but EPA revoked it in 2006 based on an absence of evidence of health effects associated with annual PM_{10} levels. In September 2006, EPA tightened the 24-hour $PM_{2.5}$ standard from 65 μg/m^3 to 35 μg/m^3. In March 2008, EPA tightened the 8-hour ozone standard from 0.08 ppm to 0.075 ppm.

When the measured concentrations of a criteria pollutant in a geographic region are less than those permitted by NAAQS, EPA designates the region as an "attainment" area for that pollutant; regions where concentrations of criteria pollutants exceed federal standards are called "nonattainment" areas. Former nonattainment areas that are now in compliance with NAAQS are designated as "maintenance" areas. Each state with a nonattainment area is required to develop and implement a State Implementation Plan (SIP) documenting how the region will reach attainment levels within periods specified in the CAA. For maintenance areas, the SIP must document how the state intends to maintain compliance with NAAQS. When EPA changes a NAAQS, each state must revise its SIP to address how it plans to attain the new standard.

NAAQS have not been established for hazardous air pollutants. Hazardous air pollutants emitted from vehicles that are known or suspected to cause cancer or other serious health and environmental effects are referred to as mobile source air toxics (MSATs).[3] The MSATs

[3] A list of all MSATs identified by EPA to date can be found in the *Regulatory Impact Analysis for Final Rule: Control of Hazardous Air Pollutants from Mobile Sources* (signed February 9, 2007), EPA420-R-07-002, Tables 1.1-1 and 1.1-2 (EPA 2007b).

included in this analysis are acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter (DPM), and formaldehyde. EPA and the Federal Highway Administration (FHWA) have identified these air toxics as the MSATs that typically are of greatest concern for impacts of highway vehicles (EPA 2007a, FHWA 2009). DPM is a component of exhaust from diesel-fueled vehicles and falls almost entirely within the $PM_{2.5}$ particle-size class. On-road mobile sources (highway vehicles) are responsible for 47,340,000 tons per year of acetaldehyde (38 percent of total U.S. emissions), 4,209,000 tons per year (15 percent) of acrolein emissions, 232,557,000 tons per year (53 percent) of benzene emissions, 26,715,000 tons per year (52 percent) of 1,3-butadiene emissions, and 84,957,000 tons per year (34 percent) of formaldehyde emissions (EPA 2009b).[4]

Concentrations of traffic-generated air pollutants can be elevated for up to 300 to 500 meters (980 to 1,640 feet) downwind of roads with high traffic volumes (Zhou and Levy 2007). Vehicle-related sources that contribute to these elevated roadside concentrations include exhaust emissions, evaporative emissions, and resuspension of road dust and tire and brake wear. Together, elevated levels of various criteria and hazardous pollutants have been shown to increase the risk of adverse health effects in populations who live, work, or attend school near major roads. Because a large percentage of the U.S. population lives in close proximity to major roads (17 percent of all homes are within 300 feet of a highway with 4 or more lanes, a railroad, or an airport [HUD, 2009]), it is important to understand how traffic-generated pollutants collectively affect the health of exposed populations. Studies have demonstrated a suggestive causal association between traffic exposure and new-onset asthma and a causal association for exacerbation of symptoms (HEI 2010, Salam et al. 2008) and cardiovascular conditions (HEI 2010, Adar and Kaufman 2007). Studies have also demonstrated associations between traffic exposure and adverse birth outcomes (HEI 2010) and childhood cancer (HEI 2010, Raaschou-Nielsen and Reynolds 2006); however, evidence of a causal or suggestively causal association is insufficient. There are also an insufficient number of well-designed studies to address associations for other health conditions. Sections 4.1.1.1 and 4.1.1.2 discuss specific health effects associated with each of the criteria and hazardous air pollutants analyzed in this EIS.

Section 3.4 addresses the major GHGs – CO_2, methane (CH_4), and N_2O; these GHGs are not included in this air quality analysis.

4.1.1.1 Health Effects of Criteria Pollutants

Sections 4.1.1.1.1 through 4.1.1.1.6 briefly describe the health effects of the six criteria pollutants. This information is adapted from the EPA Green Book, Criteria Pollutants (EPA 2011e). The most recent EPA technical reports and *Federal Register* notices for NAAQS reviews provide more information on the health effects of criteria pollutants (EPA 2011f).

4.1.1.1.1 Ozone

Ozone is a photochemical oxidant and the major component of smog. Ozone is not emitted directly into the air, but is formed through complex chemical reactions among precursor emissions of VOCs and NO_x in the presence of the ultraviolet component of sunlight. Ground-level ozone causes health problems because it irritates the mucous membranes, damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants. Ozone-related health effects also include respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, and a variety of other respiratory-related effects. Exposure to ozone for several hours at relatively low concentrations has been

[4] Nationwide total emissions data are not available for DPM.

found to substantially reduce lung function and induce respiratory inflammation in normal, healthy people during exercise. There is also evidence that short-term exposure to ozone directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality.

In addition to its human health impacts, ozone has the potential to affect the health of vegetation and ecosystems. Ozone in the atmosphere is absorbed by plants and disturbs the plant's carbon sequestration process, thereby limiting its available energy supply. Consequently, exposed plants can lose their vigor, become more susceptible to disease and other environmental stressors, and demonstrate lessened growth, visual abnormalities, or accelerated aging. According to EPA (2006b), ozone affects crops, vegetation, and ecosystems more than any other air pollutant. Ozone can produce both acute and chronic injury in sensitive species, depending on the concentration level, the duration of the exposure, and the plant species under exposure. Because of the differing sensitivities among plants to ozone, ozone pollution can also exert a selective pressure that leads to changes in plant community composition. Given the range of plant sensitivities and the fact that numerous other environmental factors modify plant uptake and response to ozone, it is not possible to identify threshold values above which ozone is consistently toxic for all plants.

VOCs, a chemical precursor to ozone, also can play a role in vegetation damage (Foster 1991). For some sensitive plants under exposure, VOCs have been demonstrated to impact seed production, photosynthetic efficiency, leaf water content, seed germination, flowering, and fruit ripening (Cape et al. 2003). NO_x, the other chemical precursor to ozone, has also been demonstrated to have impacts on vegetation health (Viskari 2000, Ugrekhelidze et al. 1997, Kammerbauer et al. 1987). Most of the studies of the impacts of VOCs and NO_x on vegetation have focused on short-term exposure, and few studies have focused on long-term effects on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

4.1.1.1.2 Particulate Matter (PM)

PM is a generic term for a broad class of chemically and physically diverse substances that exist as discrete particles. PM includes dust, dirt, soot, smoke, and liquid droplets directly emitted into the air, and particles formed in the atmosphere by condensation or by the transformation of emitted gases such as NO_x, sulfur oxides (SO_x), and VOCs. Fine particles are produced primarily by combustion processes and by these atmospheric transformations. The definition of PM also includes particles composed of elemental carbon (or black carbon). Both gasoline-fueled and diesel-fueled vehicles emit PM. In general, the smaller the PM, the deeper it can penetrate into the respiratory system and the more damage it can cause. Depending on its size and composition, PM can damage lung tissue, aggravate existing respiratory and cardiovascular diseases, alter the body's defense systems against foreign materials, and cause cancer and premature death.

PM also can contribute to poor visibility by scattering and absorbing light, consequently making the terrain appear hazy. To address visibility concerns, EPA developed the regional haze program[5], which was put in place in July 1999 to protect the visibility in Mandatory Class I Federal Areas (national parks and wilderness areas). EPA has also set secondary NAAQS to regulate non-Class I areas outside the regional haze program. Deposition of PM (especially secondary PM formed from NO_x and SO_x) can damage materials, adding to the effects of natural weathering processes by potentially promoting or accelerating the corrosion of metals,

[5] Final Rule: Regional Haze Regulations, 64 FR 35714 (July 1, 1999).

degrading paints, and deteriorating building materials (especially concrete and limestone). Section 6.3 provides more information about materials damage and soiling impacts.

As noted above, EPA regulates PM according to two particle-size classifications, PM_{10} and $PM_{2.5}$. This analysis considers only $PM_{2.5}$ because almost all of the PM emitted in exhaust from passenger cars and light trucks is $PM_{2.5}$.

4.1.1.1.3 Carbon Monoxide (CO)

CO is a colorless, odorless, poisonous gas produced by incomplete combustion of carbon in fuels. Motor vehicles are the single largest source of CO emissions nationally.[6] When CO enters the bloodstream, it acts as an asphyxiant by reducing the delivery of oxygen to the body's organs and tissues. It can affect the central nervous system and impair the brain's ability to function properly. Health threats are most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease. Epidemiologic studies show associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease. Some epidemiological studies suggest a causal relationship between long-term exposures to CO and developmental effects and adverse health effects at birth, such as decreased birth weight.

4.1.1.1.4 Lead

Lead is a toxic heavy metal used in industrial manufacturing and production, such as in battery manufacturing, and formerly was widely used as an additive in paints. Lead gasoline additives (for use in piston-engine-powered aircraft), non-ferrous smelters, and battery plants are the most significant contributors to atmospheric lead emissions. Lead exposure can occur through multiple pathways, including inhalation of air and ingestion of lead in food, water, soil, or dust. Excessive lead exposure can cause seizures, mental retardation, behavioral disorders, severe and permanent brain damage, and death. Even low doses of lead can cause central nervous system damage. Because of the prohibition of lead as an additive in motor vehicle liquid fuels, lead is no longer emitted from motor vehicles in more than negligible quantities. Lead is therefore not addressed in the analysis below.

4.1.1.1.5 Sulfur Dioxide (SO_2)

SO_2, one of various oxides of sulfur, is a gas formed from combustion of fuels containing sulfur. Most SO_2 emissions are produced by stationary sources such as power plants. SO_2 is also formed when gasoline is extracted from crude oil in petroleum refineries and in other industrial processes. High concentrations of SO_2 cause severe respiratory distress (difficulty breathing), irritate the upper respiratory tract, and aggravate existing respiratory and cardiovascular disease. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. Asthmatics are more sensitive to the effects of SO_2, likely because of preexisting inflammation associated with asthma. SO_2 also is a primary contributor to acidic deposition, or acid rain, which causes acidification of lakes and streams and can damage trees, crops, historic buildings, and statues.

[6] Highway motor vehicles overall accounted for 50 percent of national CO emissions in 2008. Passenger cars and light trucks accounted for approximately 76 percent of the CO emissions from highway motor vehicles (EPA 2009a).

4.1.1.1.6 Nitrogen Dioxide (NO_2)

NO_2 is a reddish-brown, highly reactive gas, one of the oxides of nitrogen formed by high-temperature combustion (as in vehicle engines) of nitrogen and oxygen. Most NO_x created in the combustion reaction consists of nitric oxide, which oxidizes to NO_2 in the atmosphere. NO_2 can irritate the lungs and mucous membranes, aggravate asthma, cause bronchitis and pneumonia, and lower resistance to respiratory infections. NO_2 has also been linked to other health endpoints, including all-cause (non-accidental) mortality, hospital admissions or emergency department visits for cardiovascular disease, and reductions in lung function growth associated with chronic exposure. Oxides of nitrogen are an important precursor to both ozone and acid rain, and can affect both terrestrial and aquatic ecosystems.

4.1.1.2 Health Effects of Mobile Source Air Toxics[7]

Motor vehicle emissions contribute to ambient levels of air toxics known or suspected to be human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to air toxics (EPA 2005a). These compounds include, but are not limited to, acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde. These five air toxics, plus DPM, comprise the six priority MSATs analyzed in this EIS. These compounds plus polycyclic organic matter (POM) and naphthalene were identified as national or regional risk drivers or contributors in the EPA 2005 National-scale Air Toxics Assessment and have significant inventory contributions from mobile sources (EPA 2005a). This EIS does not analyze POM separately, but POM can occur as a component of DPM and is addressed in Section 4.1.1.2.5. Naphthalene also is not analyzed separately in this EIS, but it is a member of the POM class of compounds and is also addressed in Section 4.1.1.2.5.

4.1.1.2.1 Acetaldehyde

Acetaldehyde is classified in the EPA Integrated Risk Information System (IRIS) database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes (EPA 1998). In its Twelfth Report on Carcinogens (NTP 2011), the U.S. Department of Health and Human Services (HHS) reasonably anticipates acetaldehyde to be a human carcinogen, and the International Agency for Research on Cancer (IARC) (IARC 1999) classifies acetaldehyde as possibly carcinogenic to humans (Group 2B). EPA is reassessing cancer risk from inhalation exposure to acetaldehyde and intends to end the draft development phase in early 2012; hold a period of agency, interagency, and external peer/public review; and by the end of the fourth quarter of 2012, finish the final agency review cycle.

The primary noncancer effects of exposure to acetaldehyde vapors include eye, skin, and respiratory-tract irritation (EPA 1998). In short-term (4-week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure (Appelman et al. 1982, 1986). EPA used data from these studies to develop an inhalation reference concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume and bronchoconstriction upon inhaling acetaldehyde (Myou et al. 1993). EPA is reassessing the health hazards from inhalation exposure to acetaldehyde on the same schedule as noted above for reassessing cancer risk.

[7] Preamble in Proposed Rule: Mandatory Reporting of Greenhouse Gases. 74 FR 16448 (Apr. 10, 2009).

4.1.1.2.2 Acrolein

Acrolein is extremely acrid and is irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion, and congestion. The intense irritancy of this carbonyl compound has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure (EPA 2003a). The EPA 2003 IRIS human health risk assessment for acrolein (EPA 2003a) summarizes these data and additional studies regarding acute effects of human exposure to acrolein. Evidence available from studies in humans indicate that levels as low as 0.09 ppm (0.21 milligrams per cubic meter) for 5 minutes can elicit subjective complaints of eye irritation, with increasing concentrations leading to more extensive eye, nose, and respiratory symptoms (Weber-Tschopp et al. 1977, EPA 2003a). Lesions to the lungs and upper respiratory tracts of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein (EPA 2003b). Acute exposure effects in animal studies report bronchial hyper-responsiveness (EPA 2003a). In a recent study, the acute respiratory irritant effects of exposure to 1.1 ppm acrolein were more pronounced in mice with allergic airway disease compared to non-diseased mice, which also showed decreases in respiratory rate (Morris et al. 2003). Based on these animal data and demonstration of similar effects in humans (e.g., reduction in respiratory rate), individuals with compromised respiratory function (e.g., emphysema and asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein.

EPA determined in 2003 that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans, and the animal data provided inadequate evidence of carcinogenicity (EPA 2003b). IARC determined that acrolein was not classifiable as to its carcinogenicity in humans (IARC 1995).

4.1.1.2.3 Benzene

EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice (EPA 2000a, IARC 1982, Irons et al. 1992). Data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. IARC and HHS have characterized benzene as a human carcinogen (IARC 1987, NTP 2011).

Several adverse noncancer health effects, including blood disorders such as pre-leukemia and aplastic anemia, have also been associated with long-term exposure to benzene (Aksoy 1989, Goldstein 1988). The most sensitive noncancer effect observed in humans, based on current data, is depression of the absolute lymphocyte count in blood (Rothman et al. 1996, EPA 2002a). In addition, recent work, including studies sponsored by the Health Effects Institute, provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known (Qu et al. 2002, 2003; Lan et al. 2004; Turtletaub and Mani 2003). The EPA IRIS program has not yet evaluated these new data.

4.1.1.2.4 1,3-butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans through inhalation (EPA 2002b, 2002c). IARC has determined that 1,3-butadiene is a probable human carcinogen, and HHS has characterized 1,3-butadiene as a known human carcinogen (IARC 1999, NTP 2011). Numerous experiments have demonstrated that animals and humans metabolize 1,3-butadiene into compounds that are genotoxic (capable of causing damage to a cell's genetic material such as DNA [deoxyribonucleic acid]). The specific mechanisms of 1,3-butadiene-induced carcinogenesis are not known; however, scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females could be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data on humans from which to draw conclusions about sensitive subpopulations. 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; there are no available human data on these effects. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice (Bevan et al. 1996).

4.1.1.2.5 Diesel Particulate Matter (DPM)

DPM is a component of diesel exhaust. DPM particles are very fine, with most particles smaller than 1 micron, and their small size allows inhaled DPM to reach the lungs. Particles typically have a carbon core coated with condensed organic compounds such as POM, which include mutagens and carcinogens. DPM also includes elemental carbon (or black carbon) particles emitted from diesel engines. EPA has not provided special status, such as a NAAQS or other health protective measures, for black carbon, but addresses black carbon in terms of $PM_{2.5}$ and DPM emissions. Diesel exhaust is likely to be carcinogenic to humans by inhalation from environmental exposure.

DPM can contain POM, which is generally defined as a large class of organic compounds that have multiple benzene rings and a boiling point greater than 100 degrees Celsius or 212 degrees Fahrenheit. EPA classifies many of the compounds included in the POM class as probable human carcinogens based on animal data. Polycyclic aromatic hydrocarbons (PAHs) are a subset of POM that contains only hydrogen and carbon atoms. Numerous PAHs are known or suspected carcinogens. Recent studies have found that maternal exposures to PAHs in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth, and impaired cognitive development at age 3 (Perera et al. 2003, 2006). EPA has not yet evaluated these recent studies.

4.1.1.2.6 Formaldehyde

Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys (EPA 1987). EPA is reviewing recently published epidemiological data under the IRIS program but has not announced a date for release of the review. National Cancer Institute research found an increased risk of nasopharyngeal (upper throat) cancer and lymphohematopoietic (lymph and blood cells) malignancies such as leukemia among workers exposed to formaldehyde (Hauptmann et al. 2003, 2004). In an analysis of the lymphohematopoietic cancer mortality from an extended follow up of these workers, the National Cancer Institute confirmed an association between lymphohematopoietic cancer risk and peak exposures to formaldehyde (Beane Freeman et al. 2009). A recent National Institute of Occupational Safety and Health study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde (Pinkerton 2004). Extended followup of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but did report a continuing statistically significant excess of lung cancers (Coggon et al. 2003). Recently, IARC reclassified formaldehyde as a human carcinogen (Group 1) (IARC 2006).

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (burning and watering), nose, and throat. Effects in humans from repeated exposure include respiratory-tract irritation, chronic bronchitis, and nasal epithelial lesions such as metaplasia (abnormal change in the structure of a tissue) and loss of cilia. Animal studies suggest that formaldehyde might also cause airway inflammation, including eosinophil (a type of white blood cell) infiltration into the airways. Several studies suggest that formaldehyde might increase the risk of asthma, particularly in the young (ATSDR 1999, WHO 2002).

4.1.1.3 Vehicle Emissions Standards and Conformity Regulations

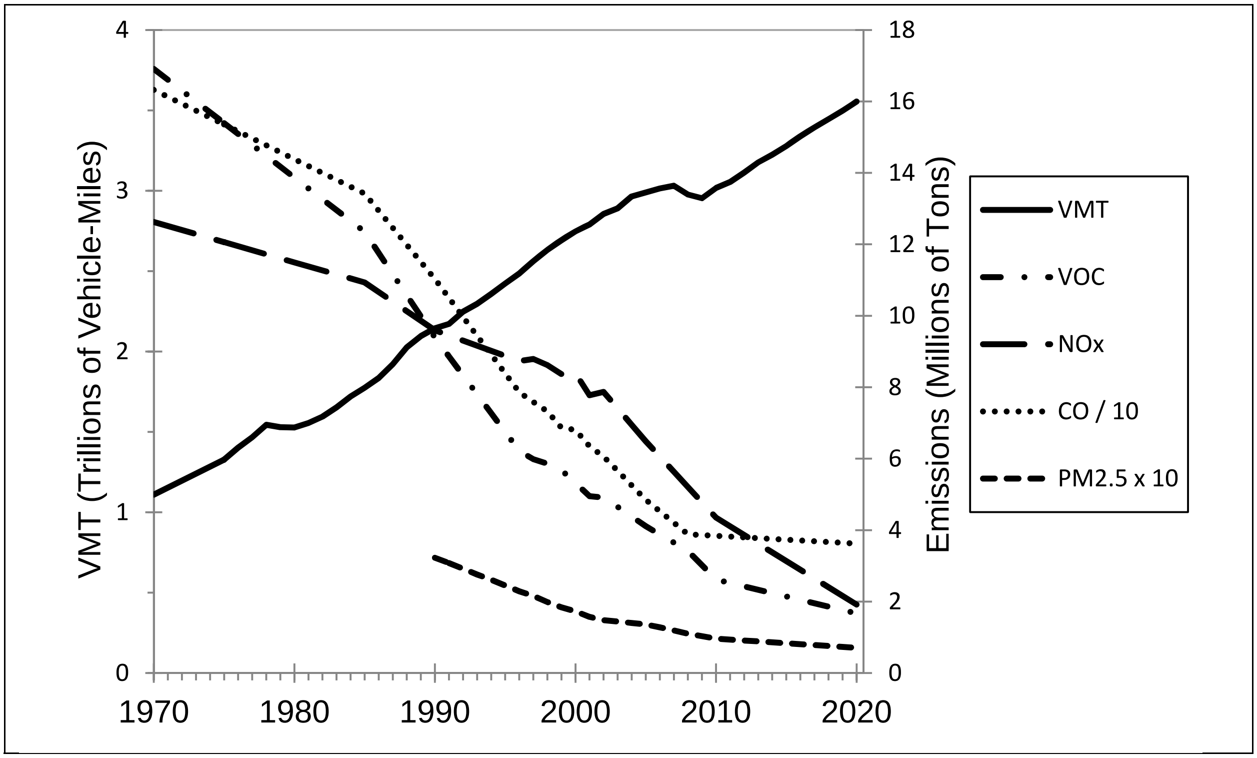
4.1.1.3.1 Vehicle Emission Standards

Under the CAA, EPA has established criteria pollutant emission standards for vehicles. EPA has tightened the emission standards over time as more effective emission-control technologies have become available. These stronger standards for passenger cars and light trucks and for heavy-duty vehicles are responsible for the declines in total criteria pollutant emissions from motor vehicles, as discussed in Section 4.1.1. The EPA Tier 2 Vehicle & Gasoline Sulfur Program, which went into effect in 2004, established the CAA emissions standards that will apply to MY 2017–2025 passenger cars and light trucks (EPA 2000b). Under the Tier 2 standards, manufacturers of passenger cars and light trucks are required to meet stricter vehicle emissions standards. As of 2004, U.S. refiners and importers of gasoline were required to manufacture gasoline with sulfur levels capped at 300 ppm, approximately a 15-percent reduction from the previous industry average of 347 ppm. By 2006, refiners met a required 30-ppm average sulfur level, with a cap of 80 ppm. These fuels enable post-2006 model year vehicles to use emission control technologies that reduce tailpipe emissions of NO_x by 77 percent for passenger cars and by as much as 95 percent for pickup trucks, vans, and sport utility vehicles compared to 2003 levels. Figure 4.1.1-1 illustrates current trends in travel and emissions from highway vehicles. Figure 4.1.1-1 does not show the effects of the Proposed Action and alternatives; *see* Section 4.2.

Since 1970, aggregate emissions traditionally associated with vehicles have decreased substantially even as vehicle miles traveled (VMT) increased by approximately 149 percent from 1970 to 1999, and approximately 220 percent from 1970 to 2010, as shown in Figure 4.1.1-1. For example, NO_x emissions, due mainly to light trucks and heavy-duty vehicles, decreased by 70 percent between 1970 and 2011, as shown in Figure 4.1.1-1. However, as future trends show, changes in vehicle travel are having a smaller and smaller impact on emissions as a result of stricter EPA standards for vehicle emissions and the chemical composition of fuels, even with additional growth in VMT (Smith 2002). This general trend will continue, to a greater or lesser degree, with implementation of any of the action alternatives.

MSATs will likely decrease in the future because of new EPA rules (EPA 2007a). These rules limit the benzene content of gasoline beginning in 2011. They also limit exhaust emissions of hydrocarbons (many VOCs and MSATs are hydrocarbons) from passenger cars, light trucks, and heavy-duty vehicles when they are operated at cold temperatures. The cold-temperature standard is being phased in from 2010 through 2015. EPA projects that these controls will substantially reduce emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde.

Figure 4.1.1-1. Vehicle Miles Traveled Compared to Vehicle Emissions[a,b]



a. Sources: Davis et al. 2011, EPA 2011c, EIA 2011a, IEC 2011.
b. VMT = vehicle miles traveled; VOCs = volatile organic compounds; NO_x = nitrogen oxides; CO = carbon monoxide; $PM_{2.5}$ = particulate matter with a diameter of 2.5 microns or less.

4.1.1.3.2 Conformity Regulations

CAA Section 176(c) prohibits federal agencies from taking or funding actions in nonattainment or maintenance areas that do not "conform" to the SIP. The purpose of this conformity requirement is to ensure that activities do not interfere with meeting the emissions targets in SIPs, do not cause or contribute to new violations of NAAQS, and do not impede the ability to attain or maintain NAAQS or delay any interim milestones. EPA has issued two sets of regulations to implement CAA Section 176(c), as follows:

- The Transportation Conformity Rules (40 CFR Part 93, Subpart A), which apply to transportation plans, programs, and projects funded or approved under U.S.C. Title 23 or the Federal Transit Laws (49 U.S.C. Chapter 53). Projects funded by the FHWA or the Federal Transit Administration (FTA) usually are subject to transportation conformity (*see* 40 CFR § 93.102).
- The General Conformity Rule (40 CFR Part 93, Subpart B) applies to all other federal actions not covered under transportation conformity. The General Conformity Rule established emissions thresholds, or *de minimis* levels, for use in evaluating the conformity of a project. If the net emission increases attributable to the project are less than these thresholds, then the project is presumed to conform and no further conformity evaluation is required. If the emissions increases exceed any of these thresholds, then a conformity determination is required. The conformity determination can entail air quality modeling studies, consultations with EPA and state air quality agencies, and commitments to revise the SIP or to implement measures to mitigate air quality impacts.

The proposed fuel economy standards and associated program activities are not funded or approved under U.S.C. Title 23 or the Federal Transit Act. Further, the proposed standards are not a highway or transit project funded or approved by the FHWA or the FTA. Accordingly, the proposed standards and associated rulemakings are not subject to transportation conformity.

Under the General Conformity Rule, a conformity determination is required where a federal action would result in total direct and indirect emissions of a criteria pollutant or precursor equaling or exceeding the rates specified in 40 CFR § 93.153(b)(1) and (2) for nonattainment and maintenance areas. As explained below, NHTSA's Proposed Action results in neither direct nor indirect emissions as defined at 40 CFR § 93.152.

The General Conformity Rule defines direct emissions as those of "a criteria pollutant or its precursors that are caused or initiated by the Federal action and originate in a nonattainment or maintenance area and occur at the same time and place as the action and are reasonably foreseeable." 40 CFR § 93.152. Because NHTSA's Proposed Action would only set fuel economy standards for passenger cars and light trucks, it causes no direct emissions within the meaning of the General Conformity Rule.

Indirect emissions under the General Conformity Rule include emissions or precursors that "(1) Are caused by the Federal action, but may occur later in time and/or may be further removed in distance from the action itself but are still reasonably foreseeable; and (2) The Federal agency can practicably control and will maintain control over due to a continuing program responsibility of the Federal agency" (40 CFR § 93.152). Each element of the definition must be met to qualify as an indirect emission. NHTSA has determined that, for purposes of general conformity, emissions as a result of the fuel economy standards would not be caused by NHTSA's action, but rather occur due to subsequent activities the agency cannot practically control. "[E]ven if a Federal licensing, rulemaking, or other approving action is a required initial step for a subsequent activity that causes emissions, such initial steps do not mean that a Federal agency can practically control any resulting emissions."[8] (40 CFR § 93.152).

NHTSA cannot control vehicle manufacturers' production of passenger cars and light trucks and consumer purchasing and driving behavior. For purposes of analyzing the environmental impacts of this proposed rule under NEPA, NHTSA has made assumptions regarding the technologies manufacturers will install and how companies will react to increased fuel economy standards. Specifically, NHTSA's NEPA analysis predicts increases in air toxic and criteria pollutants would occur in some nonattainment areas under certain alternatives based on the rebound effect. However, NHTSA's Proposed Action does not mandate specific manufacturer decisions or driver behavior. NHTSA's NEPA analysis assumes a rebound effect, wherein the Proposed Action could create an incentive for additional vehicle use by reducing the cost of fuel consumed per mile driven. This rebound effect is an estimate of how NHTSA assumes some drivers will react to the proposed rule and is useful for estimating the costs and benefits of the rule, but the agency does not have the statutory authority, or the program responsibility, to control, among other items discussed above, the actual vehicle miles traveled by drivers. Accordingly, changes in any emissions that result from NHTSA's proposed standards are not changes the agency can practicably control; therefore, the Proposed Action would cause no indirect emissions, and a general conformity determination is not required.

[8] Final Rule: Revisions to the General Conformity Regulations, 75 FR 17254 (Apr. 5, 2010).

4.1.2 Methodology

4.1.2.1 Overview

To analyze air quality and human health impacts, NHTSA calculated the emissions of criteria pollutants and MSATs from passenger cars and light trucks that would occur under each alternative. NHTSA then estimated the resulting changes in emissions under each action alternative by comparing emissions under that alternative to those under the No Action Alternative. The resulting changes in air quality and effects on human health were assumed to be proportional to the changes in emissions projected to occur under each action alternative.

The air quality analysis accounted for downstream emissions, upstream emissions, and the rebound effect, as discussed in Chapter 2. In summary, the change in emissions resulting from each alternative is the sum of (1) reductions in upstream emissions due to the decline in fuel consumption and thus a lower volume of fuel production and distribution, and (2) the increase in vehicle (downstream) emissions resulting from added vehicle use due to the fuel-efficiency rebound effect.

4.1.2.2 Regional Analysis

Over the course of the CAFE program, NHTSA has received comments requesting that the agency consider the sub-national air quality impacts of its CAFE program. NHTSA has included the following information about regional air quality impacts of the Proposed Action in response to such comments and because the agency believes that such an analysis provides valuable information for the decisionmaker and the public. Performing this analysis does not affect the agency's conclusion that a general conformity determination is not required. While a truly local analysis (i.e., at the individual roadway level) is impractical for a national EIS, NHTSA believes a regional emissions analysis still provides valuable information and is feasible for the scope of this EIS.

To assess regional differences in the effects of the alternatives, NHTSA estimated net emission changes for individual nonattainment and maintenance areas.[9] The distribution of emissions is not uniform nationwide, and either increases or decreases in emissions can occur within individual nonattainment or maintenance areas. NHTSA focused on nonattainment areas because these are the regions in which air quality problems have been greatest. All nonattainment areas assessed are in nonattainment for ozone or $PM_{2.5}$ because these are the pollutants for which emissions from passenger cars and light trucks are of greatest concern. At present, there are no NO_2 nonattainment areas, and only one area is designated as being in nonattainment for CO. There are many areas designated as being in nonattainment for SO_2 or PM_{10}. There are maintenance areas for CO, NO_2, ozone, PM_{10}, and SO_2. NHTSA did not quantify PM_{10} emissions separately from $PM_{2.5}$ because almost all the PM in the exhaust from passenger cars and light trucks is $PM_{2.5}$.[10] Appendix D provides emission estimates for all nonattainment areas for all criteria pollutants (except lead, as discussed in Section 4.1.1.1.4). The road-dust component of PM_{10} and $PM_{2.5}$ concentrations due to passenger cars and light trucks would increase in proportion to the rebound effect; however, road-dust emissions would not be regulated under this rulemaking and therefore are not assessed in this EIS. On-road motor vehicles are a minor contributor to SO_2 emissions (less than 0.39 percent of national

[9] In Section 4.1.3, where the term nonattainment is used, it includes both nonattainment areas and maintenance areas.
[10] In addition to exhaust $PM_{2.5}$, the analysis included the brake wear and tire wear components of $PM_{2.5}$.

emissions, as noted above) and are unlikely to affect the attainment status of SO_2 nonattainment and maintenance areas.

NHTSA's emissions analysis is national and regional, but does not attempt to address the specific geographic locations of increases in emissions within nonattainment areas. Emission increases due to the rebound effect consist of higher emissions from passenger cars and light trucks operating on entire regional roadway networks, so that any emission increases due to the VMT rebound effect would be distributed throughout a region's entire road network, and at any specific location would be uniformly proportional to VMT increases at that location. At any one location within a regional network, the resulting increase in emissions would be small compared to total emissions from all sources surrounding that location (including existing emissions from traffic already using the road), so the localized impacts of the Proposed Action on ambient concentrations and health should also be small. The nationwide aggregated consequences of such small near-source impacts on ambient pollutant concentrations and health might be larger, but are not feasible to quantify.

4.1.2.3 Time Frames for Analysis

Ground-level concentrations of criteria and toxic air pollutants generally respond quickly to changes in emission rates. The longest averaging period for measuring whether ambient concentrations of a pollutant comply with the NAAQS is 1 year.[11] This air quality analysis considers emissions that would occur over annual periods, consistent with the NAAQS.

To evaluate impacts to air quality, specific years must be selected for which emissions will be estimated and their effects on air quality calculated. NHTSA selected calendar years that are meaningful for the timing of likely effects of the alternatives. The analysis years selected for this analysis include:

- 2021 – First year of complete implementation of the MY 2017–2021 fuel economy standards.
- 2025 – First year of complete implementation of the MY 2017–2025 fuel economy standards.
- 2040 – A mid-term forecast year; by this point a large proportion of passenger car and light truck VMT would be accounted for by vehicles that meet the MY 2017–2025 standards.
- 2060 – By 2060, almost all passenger cars and light trucks in operation would meet the MY 2017–2025 standards, and the impact of these standards would be determined primarily by VMT growth rather than by MY 2017–2025 vehicles replacing older, less fuel-efficient vehicles.

4.1.2.4 Incomplete or Unavailable Information

Where information in the analysis included in this EIS is incomplete or unavailable, NHTSA relies on CEQ regulations regarding incomplete or unavailable information (*see* 40 CFR § 1502.22(b)). As noted throughout this methodology section, the estimates of emissions rely on models and forecasts that contain numerous assumptions and data that are uncertain. Examples of areas in which information is incomplete or unavailable include future emission

[11] Compliance with the ozone NAAQS is based on the average of the fourth highest daily maximum 8-hour concentration over a 3-year period; compliance with the 24-hour $PM_{2.5}$ NAAQS is based on the average of the daily 98th percentile concentrations averaged over a 3-year period; and compliance with the annual $PM_{2.5}$ NAAQS is based on the 3-year average of the weighted annual mean concentrations.

rates, vehicle manufacturers' decisions about vehicle technology and design, the mix of vehicle types and model years comprising the passenger car and light-truck fleet, VMT projections, emissions from fuel refining and distribution, and economic factors.

To support the information in this EIS, NHTSA used the best available models and supporting data. The models used for the EIS were subjected to scientific review and have received the approval of the agencies that sponsored their development. Nonetheless, NHTSA notes that there are limitations to current modeling capabilities. For example, uncertainties can derive from model formulation (including numerical approximations and the definition of physical and chemical processes) and inaccuracies in the input data (e.g., emission inventory estimates).

Additional limitations are associated with the estimates of health benefits. To approximate the health benefits associated with each alternative, NHTSA used screening-level estimates of health outcomes in the form of cases per ton of criteria pollutant emissions reduced, and of monetized health benefits in the form of dollars per ton of criteria pollutant emissions reduced. However, the use of such dollars-per-ton numbers does not account for all potential health and environmental benefits because the information necessary to monetize all potential health and environmental benefits is not available. Therefore, NHTSA has likely underestimated the total benefits of reducing criteria pollutants. Reductions in emissions of toxic air pollutants should result in health benefits as well, but scientific data that would support quantification and monetization of these benefits are not available.

4.1.2.5 Allocation of Exhaust Emissions to Nonattainment Areas

For each alternative, the Volpe model provided national emission estimates for each criteria air pollutant (or its chemical precursors) and MSAT. National emissions were allocated to the county level using VMT data for each county. EPA provided estimated passenger car and light truck VMT data for all counties in the United States for 2014, 2020, 2030, and 2050, consistent with EPA's National Emissions Inventory (NEI).[12] These VMT projections were based on growth in specific factors affecting passenger car and light-truck use projected for individual counties in EIA (2006). VMT data used in the NEI were estimated from traffic counts taken by counties and states on major roadways, and therefore are subject to some uncertainty. NHTSA derived VMT for the air quality analysis years 2021, 2025, 2040, and 2060 by interpolation of the EPA data. NHTSA used the estimates of county-level VMT from the NEI only to allocate nationwide total emissions to counties, and not to calculate the county-level emissions directly. The estimates of nationwide total emissions are based on the national VMT data used in the Volpe model.

NHTSA used the county-level VMT allocations, expressed as the fractions of national VMT that takes place within each county, to derive the county-level emissions from the estimates of nationwide total emissions. Emissions for each nonattainment area were then derived by summing the emissions for the counties included in each nonattainment area. Many nonattainment areas comprise one or more counties, and because county-level emissions are aggregated for each nonattainment area, uncertainties in the county-level emission estimates carry over to estimates of emissions within each nonattainment area. Over time, some counties will grow faster than others, and VMT growth rates will also vary. EPA's forecasts of county-level VMT allocation introduce some uncertainty into the nonattainment-area-level VMT estimates. Additional uncertainties that affect county-level exhaust emission estimates arise from differences among counties or nonattainment areas in factors other than VMT, such as ambient temperatures, vehicle age distributions, vehicle speed distributions, vehicle

[12] The VMT data provided by EPA are based on data generated by the Federal Highway Administration.

inspection and maintenance programs, and fuel composition requirements. This uncertainty increases as the projection period lengthens, such as for analysis years 2040 and 2060 compared to 2021 and 2025.

The geographic definitions of ozone and $PM_{2.5}$ nonattainment areas NHTSA uses in this document came from the current EPA Green Book Nonattainment Areas for Criteria Pollutants (EPA 2011e). For nonattainment areas that include portions of counties, NHTSA calculated the proportion of county population that falls within the nonattainment area boundary as a proxy for the proportion of county VMT within the nonattainment area boundary. Partial county boundaries were taken from geographic information system (GIS) files based on 2010 nonattainment area definitions. The populations of these partial-county areas were calculated using U.S. Census data applied to the boundaries mapped by GIS. This method assumes that per-capita VMT is constant in each county, so that the proportion of county-wide VMT in the partial county area reflects the proportion of total county population residing in that same area. This technique for allocating VMT to partial counties involves some additional uncertainty because actual VMT per capita can vary according to the characteristics of land use and urban development. For example, VMT per capita can be lower than average in urban centers with mass transit, and higher than average in suburban and rural areas where people tend to drive more (Cook et al. 2006).

Table 4.1.2-1 lists the current nonattainment and maintenance areas for ozone and $PM_{2.5}$ and their status/classification and general conformity threshold.

Table 4.1.2-1. Nonattainment Areas for Ozone and $PM_{2.5}$[a]

Nonattainment/Maintenance Area	Pollutant	Status[b]	General Conformity Threshold[c]
Albany-Schenectady-Troy, NY	Ozone	Former Subpart 1	50
Allegan County, MI	Ozone	Former Subpart 1	50
Allentown-Bethlehem-Easton, PA	Ozone	Maintenance	100
Altoona, PA	Ozone	Maintenance	100
Amador and Calaveras Counties (Central Mountain), CA	Ozone	Former Subpart 1	50
Atlanta, GA	Ozone	Moderate	50
Atlanta, GA	$PM_{2.5}$	Nonattainment	100
Baltimore, MD	Ozone	Moderate	50
Baltimore, MD	$PM_{2.5}$	Nonattainment	100
Baton Rouge, LA	Ozone	Moderate	50
Beaumont-Port Arthur, TX	Ozone	Moderate	50
Benton Harbor, MI	Ozone	Maintenance	100
Benzie County, MI	Ozone	Maintenance	100
Berkeley and Jefferson Counties, WV	Ozone	Maintenance	100
Birmingham, AL	Ozone	Maintenance	100
Birmingham, AL	$PM_{2.5}$	Nonattainment	100
Boston-Lawrence-Worcester (eastern MA), MA	Ozone	Moderate	50
Boston-Manchester-Portsmouth (southeast NH), NH	Ozone	Moderate	50
Buffalo-Niagara Falls, NY	Ozone	Former Subpart 1	50
Canton-Massillon, OH	Ozone	Maintenance	100

Table 4.1.2-1. Nonattainment Areas for Ozone and $PM_{2.5}$[a] (continued)

Nonattainment/Maintenance Area	Pollutant	Status[b]	General Conformity Threshold[c]
Canton-Massillon, OH	$PM_{2.5}$	Nonattainment	100
Case County, MI	Ozone	Maintenance	100
Charleston, WV	Ozone	Maintenance	100
Charleston, WV	$PM_{2.5}$	Nonattainment	100
Charlotte-Gastonia-Rock Hill, NC-SC	Ozone	Moderate	50
Chattanooga, TN-GA-AL	$PM_{2.5}$	Nonattainment	100
Chattanooga, TN-GA	Ozone	Former Subpart 1	50
Chicago-Gary-Lake County, IL-IN	Ozone	Moderate	50
Chicago-Gary-Lake County, IL-IN	$PM_{2.5}$	Nonattainment	100
Chico, CA	Ozone	Former Subpart 1	50
Cincinnati-Hamilton, OH-KY-IN	Ozone	Former Subpart 1	50
Cincinnati-Hamilton, OH-KY-IN	$PM_{2.5}$	Nonattainment	100
Clarksville-Hopkinsville, TN-KY	Ozone	Maintenance	100
Clearfield and Indiana Counties, PA	Ozone	Maintenance	100
Cleveland-Akron-Lorain, OH	Ozone	Maintenance	100
Cleveland-Akron-Lorain, OH	$PM_{2.5}$	Nonattainment	100
Columbia, SC	Ozone	Former Subpart 1	50
Columbus, OH	Ozone	Maintenance	100
Columbus, OH	$PM_{2.5}$	Nonattainment	100
Dallas-Fort Worth, TX	Ozone	Moderate	50
Dayton-Springfield, OH	Ozone	Maintenance	100
Dayton-Springfield, OH	$PM_{2.5}$	Nonattainment	100
Denver-Boulder-Greeley-Fort Collins-Loveland, CO	Ozone	Former Subpart 1	50
Detroit-Ann Arbor, MI	Ozone	Maintenance	100
Detroit-Ann Arbor, MI	$PM_{2.5}$	Nonattainment	100
Door County, WI	Ozone	Former Subpart 1	50
Erie, PA	Ozone	Maintenance	100
Essex County (Whiteface Mountain), NY	Ozone	Former Subpart 1	50
Evansville, IN	Ozone	Maintenance	100
Evansville, IN	$PM_{2.5}$	Nonattainment	100
Fayetteville, NC	Ozone	Former Subpart 1	50
Flint, MI	Ozone	Maintenance	100
Fort Wayne, IN	Ozone	Maintenance	100
Franklin County, PA	Ozone	Maintenance	100
Frederick County, VA	Ozone	Former Subpart 1	50
Fredericksburg, VA	Ozone	Maintenance	100
Grand Rapids, MI	Ozone	Maintenance	100
Greater Connecticut, CT	Ozone	Moderate	50
Greene County, IN	Ozone	Maintenance	100
Greene County, PA	Ozone	Maintenance	100

Table 4.1.2-1. Nonattainment Areas for Ozone and $PM_{2.5}$[a] (continued)

Nonattainment/Maintenance Area	Pollutant	Status[b]	General Conformity Threshold[c]
Greensboro-Winston Salem-High Point, NC	Ozone	Marginal	50
Greensboro-Winston Salem-High Point, NC	$PM_{2.5}$	Nonattainment	100
Greenville-Spartanburg-Anderson, SC	Ozone	Former Subpart 1	50
Hancock-Knox-Lincoln-Waldo Counties, ME	Ozone	Maintenance	100
Harrisburg-Lebanon-Carlisle, PA	Ozone	Maintenance	100
Harrisburg-Lebanon-Carlisle, PA	$PM_{2.5}$	Nonattainment	100
Haywood and Swain Counties (Great Smoky Mountain National Park), NC	Ozone	Maintenance	100
Hickory, NC	$PM_{2.5}$	Nonattainment	100
Hickory-Morgantown-Lenoir, NC	Ozone	Former Subpart 1	50
Houston-Galveston-Brazoria, TX	Ozone	Severe	25
Huntington-Ashland, WV-KY-OH	$PM_{2.5}$	Nonattainment	100
Huntington-Ashland, WV-KY	Ozone	Maintenance	100
Huron County, MI	Ozone	Maintenance	100
Imperial County, CA	Ozone	Moderate	50
Indianapolis, IN	Ozone	Maintenance	100
Indianapolis, IN	$PM_{2.5}$	Nonattainment	100
Jackson County, IN	Ozone	Maintenance	100
Jamestown, NY	Ozone	Former Subpart 1	50
Jefferson County, NY	Ozone	Moderate	50
Johnson City-Kingsport-Bristol, TN	Ozone	Former Subpart 1	50
Johnstown, PA	Ozone	Maintenance	100
Johnstown, PA	$PM_{2.5}$	Nonattainment	100
Kalamazoo-Battle Creek, MI	Ozone	Maintenance	100
Kansas City, MO-KS	Ozone	Maintenance	N/A
Kent and Queen Anne's Counties, MD	Ozone	Maintenance	100
Kern County (Eastern Kern), CA	Ozone	Former Subpart 1	50
Kewaunee County, WI	Ozone	Maintenance	100
Knoxville, TN	Ozone	Former Subpart 1	50
Knoxville, TN	$PM_{2.5}$	Nonattainment	100
Lancaster, PA	Ozone	Maintenance	100
Lancaster, PA	$PM_{2.5}$	Nonattainment	100
Lansing-East Lansing, MI	Ozone	Maintenance	100
La Porte, IN	Ozone	Maintenance	100
Las Vegas, NV	Ozone	Former Subpart 1	50
Libby, MT	$PM_{2.5}$	Nonattainment	100
Liberty-Clairton, PA	$PM_{2.5}$	Nonattainment	100
Lima, OH	Ozone	Maintenance	100
Los Angeles South Coast Air Basin, CA	Ozone	Extreme	10
Los Angeles South Coast Air Basin, CA	$PM_{2.5}$	Nonattainment	100

Table 4.1.2-1. Nonattainment Areas for Ozone and $PM_{2.5}$[a] (continued)

Nonattainment/Maintenance Area	Pollutant	Status[b]	General Conformity Threshold[c]
Los Angeles-San Bernardino Counties (western Mohave), CA	Ozone	Moderate	50
Louisville, KY-IN	Ozone	Maintenance	100
Louisville, KY-IN	$PM_{2.5}$	Nonattainment	100
Macon, GA	Ozone	Maintenance	100
Macon, GA	$PM_{2.5}$	Nonattainment	100
Madison and Page Counties (Shenandoah NP), VA	Ozone	Maintenance	100
Manitowoc County, WI	Ozone	Former Subpart 1	50
Mariposa and Tuolumne Counties (Southern Mountain), CA	Ozone	Former Subpart 1	50
Martinsburg, WV-Hagerstown, MD	$PM_{2.5}$	Nonattainment	100
Mason County, MI	Ozone	Maintenance	100
Memphis, TN-AR	Ozone	Maintenance	100
Milwaukee-Racine, WI	Ozone	Moderate	50
Muncie, IN	Ozone	Maintenance	100
Murray County (Chattahoochee NF), GA	Ozone	Maintenance	100
Muskegon, MI	Ozone	Maintenance	100
Nashville, TN	Ozone	Former Subpart 1	50
Nevada County (western part), CA	Ozone	Former Subpart 1	50
New York-N. New Jersey-Long Island, NY-NJ-CT	$PM_{2.5}$	Nonattainment	100
New York-N. New Jersey-Long Island, NY-NJ-CT	Ozone	Moderate	50
Norfolk-Virginia Beach-Newport News, VA	Ozone	Maintenance	100
Parkersburg-Marietta, WV-OH	Ozone	Maintenance	100
Parkersburg-Marietta, WV-OH	$PM_{2.5}$	Nonattainment	100
Philadelphia-Wilmington, PA-NY-DE	$PM_{2.5}$	Nonattainment	100
Philadelphia-Wilmington-Atlantic City, PA-NY-MD-DE	Ozone	Moderate	50
Phoenix-Mesa, AZ	Ozone	Former Subpart 1	50
Pittsburgh-Beaver Valley, PA	Ozone	Former Subpart 1	50
Pittsburgh-Beaver Valley, PA	$PM_{2.5}$	Nonattainment	100
Portland, ME	Ozone	Maintenance	100
Poughkeepsie, NY	Ozone	Moderate	50
Providence (entire State), RI	Ozone	Moderate	50
Raleigh-Durham-Chapel Hill, NC	Ozone	Maintenance	100
Reading, PA	Ozone	Maintenance	100
Reading, PA	$PM_{2.5}$	Nonattainment	100
Richmond-Petersburg, VA	Ozone	Maintenance	100
Riverside County (Coachella Valley), CA	Ozone	Severe	25
Roanoke, VA	Ozone	Former Subpart 1	50
Rochester, NY	Ozone	Former Subpart 1	50
Rocky Mount, NC	Ozone	Maintenance	100
Rome, GA	$PM_{2.5}$	Nonattainment	100
Sacramento Metro, CA	Ozone	Severe	25

Table 4.1.2-1. Nonattainment Areas for Ozone and $PM_{2.5}$[a] (continued)

Nonattainment/Maintenance Area	Pollutant	Status[b]	General Conformity Threshold[c]
San Antonio, TX	Ozone	Former Subpart 1	50
San Diego, CA	Ozone	Former Subpart 1	50
San Francisco Bay Area, CA	Ozone	Marginal	50
San Joaquin Valley, CA	Ozone	Extreme	10
San Joaquin Valley, CA	$PM_{2.5}$	Nonattainment	100
Scranton-Wilkes Barre, PA	Ozone	Maintenance	100
Sheboygan, WI	Ozone	Moderate	50
South Bend-Elkhart, IN	Ozone	Maintenance	100
Springfield (western MA), MA	Ozone	Moderate	50
St Louis, MO-IL	Ozone	Moderate	50
St. Louis, MO-IL	$PM_{2.5}$	Nonattainment	100
State College, PA	Ozone	Maintenance	100
Steubenville-Weirton, OH-WV	Ozone	Maintenance	100
Steubenville-Weirton, OH-WV	$PM_{2.5}$	Nonattainment	100
Sutter County (Sutter Buttes), CA	Ozone	Former Subpart 1	50
Terre Haute, IN	Ozone	Maintenance	100
Tioga County, PA	Ozone	Maintenance	100
Toledo, OH	Ozone	Maintenance	100
Ventura County, CA	Ozone	Serious	50
Washington County (Hagerstown), MD	Ozone	Former Subpart 1	50
Washington, DC-MD-VA	Ozone	Moderate	50
Washington, DC-MD-VA	$PM_{2.5}$	Nonattainment	100
Wheeling, WV-OH	Ozone	Maintenance	100
Wheeling, WV-OH	$PM_{2.5}$	Nonattainment	100
York, PA	Ozone	Maintenance	100
York, PA	$PM_{2.5}$	Nonattainment	100
Youngstown-Warren-Sharon, OH-PA	Ozone	Maintenance	100

a. Source: EPA 2011e. $PM_{2.5}$ = particulate matter with a nominal aerodynamic diameter equal to or less than 2.5 microns
b. Pollutants for which the area is designated in nonattainment or maintenance as of 2010, and severity classification.
c. Tons per year of volatile organic compounds or nitrogen oxides in ozone maintenance and nonattainment areas; primarily $PM_{2.5}$ in $PM_{2.5}$ maintenance and nonattainment areas. N/A = conformity does not apply.

4.1.2.6 Allocation of Upstream Emissions to Nonattainment Areas

Upstream emissions associated with the production and distribution of fuels used by motor vehicles are generated when fuel products are produced, processed, and transported. Upstream emissions are typically divided into four categories: feedstock recovery, feedstock transportation, fuel refining, and fuel transportation, storage, and distribution (TS&D). Feedstock recovery refers to the extraction or production of fuel feedstocks – the materials (e.g., crude oil) that are the main inputs to the refining process. In the case of petroleum, this is the stage of crude-oil extraction. During the next stage, feedstock transportation, crude oil or other feedstocks are shipped to fuel refineries. Fuel refining refers to the processing of crude oil into gasoline and diesel fuel. TS&D refers to the movement of gasoline and diesel from refineries to bulk terminals, storage at bulk terminals, and transportation of fuel from bulk terminals to retail outlets.[13] Emissions of pollutants at each stage are associated with expenditure of energy and with leakage or spillage and evaporation of fuel products.

Although not specifically required to do so by the CAA, NHTSA has allocated upstream emissions to individual nonattainment areas to provide additional information in its regional air quality analysis to the decisionmaker and the public, consistent with previous CAFE EISs. As noted below, NHTSA made a number of important assumptions in order to carry out this analysis due to uncertainty over the accuracy of the allocation of upstream emissions. NHTSA will continue to consider the effect of this uncertainty on the impacts reported in this section as it prepares the Final EIS.

To analyze the impact of the alternatives on individual nonattainment areas, NHTSA allocated emission reductions to geographic areas according to the following methodology:

- Feedstock recovery – NHTSA assumed that little to no extraction of crude oil occurs in nonattainment areas. Of the top 50 highest producing oil fields in the United States, only 9 are in nonattainment areas. These 9 fields account for just 10 percent of domestic production, or 3 percent of total crude-oil imports plus domestic production (EIA 2006, 2008). Therefore, because relatively little extraction occurs in nonattainment areas, NHTSA did not account for emission reductions from feedstock recovery in nonattainment areas.
- Feedstock transportation – NHTSA assumed that little to no crude oil is transported through nonattainment areas. Most refineries are outside or on the outskirts of urban areas. Crude oil is typically transported hundreds of miles from extraction points and ports to reach refineries. Most transportation is by ocean tanker and pipeline. Probably only a very small proportion of criteria pollutants emitted in the transport of crude oil occur in nonattainment areas. Therefore, NHTSA did not consider emission reductions from feedstock transportation within nonattainment areas.

Because NHTSA did not account for emission changes from the first two upstream stages, the assumptions produce conservative estimates of emission reductions in nonattainment areas (i.e., the estimates slightly underestimate the emission reductions associated with lower fuel production and use).

- Fuel refining – Fuel refining is the largest source of upstream emissions of criteria pollutants. Depending on the specific fuel and pollutant, fuel refining accounts for between one-third and three-quarters of all upstream emissions per unit of fuel produced and distributed (based on EPA modeling using GREET). NHTSA used projected emission data from the EPA 2005-based air quality modeling platform (EPA 2005b) to allocate reductions in nationwide total emissions from fuel refining to individual nonattainment areas. These EPA data were for 2022, the most representative year available in the EPA dataset. The EPA NEI includes estimates of emissions of criteria and toxic pollutants by county and by source category. Because fuel refining represents a separate source category in the NEI, it is possible to estimate the share of nationwide emissions from fuel refining that occurs within each nonattainment area. This analysis assumes that the share of fuel-refining emissions allocated to each nonattainment area does not change over time, which in effect means that fuel-refining emissions are assumed to change uniformly across all refineries nationwide as a result of each alternative.

[13] Emissions that occur while vehicles are being refueled at retail stations are included in estimates of emissions from vehicle operation.

- TS&D – NHTSA used data from the EPA modeling platform (EPA 2010a) to allocate TS&D emissions to nonattainment areas in the same way as for fuel-refining emissions. NHTSA's analysis assumes that the share of TS&D emissions allocated to each nonattainment area does not change over time, and that TS&D emissions will change uniformly nationwide as a result of the alternatives.

The emission inventories provided by the EPA air quality modeling platform (EPA 2010a) do not include county-level data for acetaldehyde, benzene, and formaldehyde. Therefore, for these three pollutants, NHTSA allocated national emissions based on the allocation of the pollutant believed to behave most similarly to the pollutant in question, as follows:

- For acetaldehyde, the data provided by EPA did not report TS&D emissions at the national or county level, so NHTSA assumed there are no acetaldehyde emissions associated with TS&D (i.e., 100 percent of upstream acetaldehyde emissions come from refining. This assumption enables the analysis to account for all upstream acetaldehyde emissions in the absence of data on the proportion attributable to TS&D). EPA's data included national fuel-refining emissions of acetaldehyde, but data by county are not available. To allocate acetaldehyde emissions to counties, NHTSA used the county allocation of acrolein, because acrolein is the toxic air pollutant which has, among those for which county-level data were available, the highest proportion of its emissions coming from refining. Thus, the use of acrolein data for allocation of acetaldehyde emissions to counties is most consistent with the assumption that 100 percent of acetaldehyde emissions come from refining.
- For benzene, the data provided by EPA data included nationwide fuel-refining and TS&D emissions, and TS&D emissions at the county level, but not refining emissions at the county level. To allocate fuel-refining emissions of benzene to counties, NHTSA used the same county allocation as 1,3-butadiene because, among toxic air pollutants for which county-level data were available, 1,3-butadiene has the ratio of fuel-refining and TS&D emissions closest to the ratio for benzene emissions.
- For formaldehyde, the data provided by EPA data included national fuel-refining and TS&D emissions, but county-level data were not available. To allocate formaldehyde emissions to counties, NHTSA used the same county allocation as for 1,3-butadiene because, among toxic air pollutants for which county-level data were available, 1,3-butadiene has the ratio of fuel refining and TS&D emissions closest to the ratio for formaldehyde emissions.

4.1.2.7 Health Outcomes and Monetized Benefits

4.1.2.7.1 Overview

This section describes NHTSA's approach to providing quantitative estimates of adverse health effects of conventional air pollutants associated with each alternative.

In this analysis, NHTSA quantified and monetized the impacts on human health anticipated to result from the changes in pollutant emissions and related changes in human exposure to air pollutants under each alternative. NHTSA evaluated the changes in four health impacts that would result from increased fuel efficiency – premature mortality, chronic bronchitis, respiratory emergency-room visits, and work-loss days. This methodology estimates the health impacts of each alternative for each analysis year, expressed as the number of additional or avoided adverse health outcomes per year.

Health and monetary outcomes are calculated from factors for each primary pollutant, (NO_x, directly emitted $PM_{2.5}$, SO_2, and VOCs) expressed as adverse health outcomes avoided or monetized health benefits gained per ton of reduced emissions. The general approach to calculating the health outcomes associated with each alternative is to multiply these factors by the estimated annual reduction in emissions of that pollutant, and to sum the results of these calculations for all pollutants. This calculation provides the total health impacts and monetized health benefits that would be achieved under each alternative. In calculating the health impacts and monetized health benefits of emission reductions, NHTSA estimated only the $PM_{2.5}$-related human health impacts expected to result from reduced population exposure to atmospheric concentrations of $PM_{2.5}$. Three other pollutants – NO_x, SO_2, and VOCs – are included in the analysis as precursor emissions that contribute to $PM_{2.5}$ not emitted directly from a source, but instead formed by chemical reactions in the atmosphere (secondary $PM_{2.5}$). While this analysis estimates PM-related incidence of four health endpoints, the monetized PM-related benefits includes the value of both PM-related mortality and morbidity health endpoints. Finally, the approach does not include any reductions in health impacts resulting from lower population exposure to other criteria air pollutants (particularly ozone) and air toxics.

4.1.2.7.2 Monetized Health Impacts

The benefit-per-ton factors represent the total monetized human health benefits due to a suite of monetized PM-related health impacts, for each ton of emissions reduced. The factors are specific to an individual pollutant and source. The $PM_{2.5}$ benefit-per-ton estimates apply to directly-emitted $PM_{2.5}$ or its precursors (e.g., NO_x, SO_2, and VOCs) . NHTSA followed the benefit-per-ton technique used in EPA's Ozone NAAQS Regulatory Impact Analysis (RIA) (EPA 2008a), Portland Cement National Emission Standards for Hazardous Air Pollutants RIA (EPA 2009c), and NO_2 NAAQS (EPA 2009d). Table 4.1.2-2 lists the quantified $PM_{2.5}$-related benefits captured in those benefit-per-ton estimates, as well as potential $PM_{2.5}$-related benefits that were not quantified in this analysis.

Table 4.1.2-2. Human Health and Welfare Effects of $PM_{2.5}$

Effects Monetized in Primary Estimates	Unquantified Effects
Adult premature mortality Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work-loss days Asthma exacerbations (asthmatic population) Infant mortality	Changes in: Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Visibility Household soiling

The benefits estimates use the concentration-response functions[14] as reported in the epidemiology literature. Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult EPA's Technical Support

[14] Concentration-response functions measure the relationship between exposure to pollution as a cause and specific outcomes as an effect, e.g., the incremental number of hospitalizations that would result from exposure of a population to a specified concentration of an air pollutant over a specified time period.

Document accompanying the final ozone NAAQS RIA (EPA 2008a). Readers can also consult Fann et al. (2009) for a detailed description of the benefit-per-ton methodology.[15]

As described in the documentation for the benefit-per-ton estimates cited above, EPA developed national per-ton estimates for selected pollutants emitted through stationary and mobile activity. Because the per-ton values vary slightly between the two categories, the total health and monetized health impacts were derived by multiplying the stationary per-ton estimates by total upstream emissions, and the mobile per-ton estimates by total mobile emissions. NHTSA's estimate of $PM_{2.5}$ benefits is therefore based on the total direct $PM_{2.5}$ and $PM_{2.5}$-related precursor emissions controlled by sector and multiplied by this per-ton value.

The benefit-per-ton coefficients were derived using modified versions of the health impact functions used in the EPA RIA for the PM NAAQS (EPA 2006a). Specifically, EPA's analysis incorporated functions directly from the epidemiology studies without an adjustment for an assumed threshold. A threshold represents the pollutant concentration below which health impacts do not occur. Although Fann et al. (2009) assumed there was a threshold in PM-related models of health impacts, EPA's updated methodology does not include this assumption. As a result, EPA's methodology assumes that very low $PM_{2.5}$ concentrations result in health risks that are correspondingly low but not zero.[16]

PM-related mortality provides most of the monetized value in each benefit-per-ton estimate. EPA calculated the premature-mortality-related effect coefficients that underlie the benefits-per-ton estimates from epidemiology studies that examined two large population cohorts – the American Cancer Society cohort (Pope et al. 2002) and the Harvard Six Cities cohort (Laden et al. 2006). These are logical choices for anchor points when presenting PM-related benefits because, although the benefit-per-ton results vary between the two studies, EPA considers Pope et al. (2002) and Laden et al. (2006) to be co-equal in terms of strengths and weaknesses and the quality of results. According to EPA, both studies should be used to generate benefits estimates. Throughout the discussion of mortality in this section, the mortality rates calculated from each of these studies are presented side by side.

The benefits-per-ton estimates used in this analysis are based on the above mortality health outcome factors, combined with economic VSL estimates provided by DOT (DOT 2011a). Departmental guidance on valuing reduction of fatalities was first published in 1993, and subsequently updated in 2008 on the basis of later research. Since then, DOT has updated this VSL to year 2011 values, in accordance with changes in prices and incomes over the past two

[15] Note that since the publication of Fann et al. (2009), EPA has made two significant changes to its benefits methods: (1) EPA no longer assumes that there is a threshold in PM-related models of health impacts and (2) EPA has revised the value of a statistical life (VSL) to equal $6.3 million (in year 2000 dollars), up from an estimate of $5.5 million (in year 2000 dollars) used in Fann et al. (2009). (VSL refers to the aggregate estimated value of reducing small risks across a large number of people. It is based on how people themselves would value reducing these risks.) NHTSA's analysis follows this EPA method except that NHTSA uses DOT's estimate of the value of VSL as discussed in this section (DOT 2011a).

[16] Based on a review of the current body of scientific literature, EPA estimates PM-related mortality without applying an assumed concentration threshold. EPA's Integrated Science Assessment for Particulate Matter (EPA 2009h), which was reviewed by EPA's Clean Air Scientific Advisory Committee (EPA 2009h; EPA 2008c), concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function. This assumption is incorporated into the calculation of the PM-related benefits-per-ton values.

years. DOT currently estimates the VSL at $6.2 million in 2011 dollars. Table 4.1.2-3 lists the dollar-per-ton estimates used in this analysis.[17]

Table 4.1.2-3. Benefit-per-ton Values (in 2011 dollars) Adjusted to Reflect DOT's Assumed VSL[a]

Year[b]	All Sources[c]		Stationary Sources[d]		Mobile Sources	
	SO_2	VOCs	NO_x	Direct $PM_{2.5}$	NO_x	Direct $PM_{2.5}$
3-Percent Discount Rate						
Mortality (ages 30 and older), Pope et al. (2002)						
2021	$26,000	$1,000	$4,300	$200,000	$4,500	$240,000
2025	$28,000	$1,100	$4,600	$210,000	$4,800	$260,000
2040	$35,000	$1,500	$6,000	$270,000	$6,300	$340,000
2060	$35,000	$1,500	$6,000	$270,000	$6,300	$340,000
Mortality (ages 30 and older), Laden et al. (2006)						
2021	$63,000	$2,600	$11,000	$490,000	$11,000	$590,000
2025	$68,000	$2,800	$11,000	$520,000	$12,000	$640,000
2040	$85,687	$3,700	$15,000	$660,000	$15,000	$840,000
2060	$86,000	$3,700	$15,000	$660,000	$15,000	$840,000
7-Percent Discount Rate						
Mortality (ages 30 and older), Pope et al. (2002)						
2021	$23,000	$970	$3,900	$180,000	$4,000	$230,000
2025	$25,000	$1,000	$4,200	$190,000	$4,400	$240,000
2040	$32,000	$1,400	$5,400	$250,000	$5,700	$310,000
2060	$32,000	$1,400	$5,400	$250,000	$5,700	$310,000
Mortality (ages 30 and older), Laden et al. (2006)						
2021	$57,000	$2,400	$9,500	$440,000	$9,900	$550,000
2025	$61,000	$2,500	$10,000	$470,000	$11,000	$590,000
2040	$78,000	$3,300	$13,000	$600,000	$14,000	$760,000
2060	$78,000	$3,300	$13,000	$600,000	$14,000	$760,000

a. NO_x = nitrogen oxides; SO_2 = sulfur dioxide; $PM_{2.5}$ = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; VOCs = volatile organic compounds.
b. Benefit-per-ton values were estimated for 2015, 2020, and 2030. For 2021 and 2025, values were interpolated exponentially between 2020 and 2030. For 2040, values were extrapolated exponentially based on the growth between 2020 and 2030. For 2060, values were held constant from 2040 values. All values have been rounded.
c. Note that the benefit-per-ton value for SO_2 is based on the value for stationary sources other than electric generating units; no SO_2 value was estimated for mobile sources. The benefit-per-ton value for VOCs was estimated across all sources.
d. Other than electric generating units (power plants).

The benefit-per-ton estimates are subject to several assumptions and uncertainties, as follows:

- The benefit-per-ton estimates used in this analysis incorporate projections of key variables, including atmospheric conditions, source level emissions, population, health baselines and

[17] The VSL derived by DOT and used for this EIS is $6.2 million in year 2011 dollars. These values agree reasonably closely with the VSL adopted by EPA in the 2010 Update of the Guidelines for Preparing Economic Analyses (EPA 2010b), estimated at $7.8 million in 2009 dollars. The discrepancy between these estimates is not unexpected, because no single dollar value has been accepted in the academic community or across the Federal Government.

incomes, technology. These projections introduce some uncertainties to the benefit per ton estimates.

- These estimates do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an overestimate or underestimate of the actual benefits of controlling fine particulates. Emission changes and benefit-per-ton estimates alone are not a precise indication of local or regional air quality and health impacts because there could be localized impacts associated with the Proposed Action. Because the atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone, and air toxics is very complex, full-scale photochemical air quality modeling is necessary to control for local variability. Full-scale photochemical modeling provides the needed spatial and temporal detail to more completely and accurately estimate changes in ambient levels of these pollutants and their associated health and welfare impacts. This modeling provides insight into the uncertainties associated with the use of benefit-per-ton estimates.
- NHTSA assumed that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from stationary sources might differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources. However, there are no clear scientific grounds to support estimating differential effects by particle type.
- NHTSA assumed that the health impact (concentration-response) function for fine particles is linear within the range of ambient concentrations under consideration. Therefore, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5}$, including regions that are in attainment with the fine-particle standard and those that do not meet the standard, down to the lowest modeled concentrations.
- Other uncertainties associated with the health impact functions include: within-study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across-study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings, and in some cases the differences are substantial); the application of concentration-response functions nationwide (does not account for any relationship between region and health effect, to the extent that there is such a relationship); and extrapolation of impact functions across population (NHTSA assumed that certain health impact functions applied to age ranges broader than those considered in the original epidemiological study). These uncertainties could under- or over-estimate benefits.
- There are several health-benefits categories NHTSA was unable to quantify due to limitations associated with using benefit-per-ton estimates, several of which could be substantial. Because NO_x and VOCs are also precursors to ozone, reductions in NO_x and VOC emissions would also reduce ozone formation and the health effects associated with ozone exposure. Unfortunately, there are no benefit-per-ton estimates because of the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. The PM-related benefit-per-ton estimates also do not include any human welfare or ecological benefits due to limitations on the availability of data to quantify these effects of pollutant emissions.

The RIA for the final $PM_{2.5}$ NAAQS (EPA 2006a) provides further information about the overall uncertainty in $PM_{2.5}$ benefits estimates.

4.1.2.7.3 Quantified Health Impacts

Table 4.1.2-4 lists the incidence-per-ton estimates for select PM-related health impacts (derived by the same process as described above for the dollar-per-ton estimates). For the analysis of direct and indirect impacts (*see* Section 4.2.1) and cumulative impacts (*see* Section 4.2.2), NHTSA used the values for 2021, 2025, 2040, and 2060 (*see* Section 4.1.2.3).

Table 4.1.2-4. Incidence-per-ton Values for Health Outcomes[a,b]

Outcome and Year[c]	All Sources[d]		Stationary Sources[e]		Mobile Sources	
	SO_2	VOCs	NO_x	Direct $PM_{2.5}$	NO_x	Direct $PM_{2.5}$
Premature Mortality						
2021	0.0035104035	0.0001457593	0.0005801679	0.0270955066	0.0006061440	0.0331811737
2025	0.0037173345	0.0001552068	0.0006173945	0.0286153483	0.0006466903	0.0353498335
2040	0.0044933256	0.0001906348	0.0007569943	0.0343147546	0.0007987392	0.0434823075
2060	0.0044933256	0.0001906348	0.0007569943	0.0343147546	0.0007987392	0.0434823075
Premature Mortality – Laden et al. (2006)						
2021	0.0089988138	0.0003740400	0.0014888337	0.0694727045	0.0015538608	0.0851037230
2025	0.0095217733	0.0003979224	0.0015828501	0.0733127312	0.0016561450	0.0905861087
2040	0.0114828715	0.0004874814	0.0019354115	0.0877128310	0.0020397108	0.1111450551
2060	0.0114828715	0.0004874814	0.0019354115	0.0877128310	0.0020397108	0.1111450551
Chronic Bronchitis						
2021	0.0024055463	0.0001023039	0.0004217800	0.0183488438	0.0004408958	0.0235551886
2025	0.0025012984	0.0001065498	0.0004403295	0.0190431008	0.0004608627	0.0245785837
2040	0.0028603691	0.0001224718	0.0005098898	0.0216465645	0.0005357386	0.0284163154
2060	0.0028603691	0.0001224718	0.0005098898	0.0216465645	0.0005357386	0.0284163154
Emergency Room Visits – Respiratory						
2021	0.0032604950	0.0001079846	0.0004739106	0.0267517217	0.0004639658	0.0269131875
2025	0.0033811644	0.0001117557	0.0004903325	0.0277109109	0.0004808543	0.0279197760
2040	0.0038336749	0.0001258975	0.0005519148	0.0313078705	0.0005441861	0.0316944828
2060	0.0038336749	0.0001258975	0.0005519148	0.0313078705	0.0005441861	0.0316944828
Work-Loss Days						
2021	0.4488013904	0.0191539328	0.0800821743	3.4328917338	0.0837563171	4.4231975782
2025	0.4578329216	0.0195173244	0.0818057725	3.4997171779	0.0856397276	4.5237084013
2040	0.4917011636	0.0208800429	0.0882692658	3.7503125933	0.0927025166	4.9006239880
2060	0.4917011636	0.0208800429	0.0882692658	3.7503125933	0.0927025166	4.9006239880

a. Source: Pope et al. 2002, except as noted.
b. NO_x = nitrogen oxides; SO_2 = sulfur dioxide; $PM_{2.5}$ equal particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; VOCs = volatile organic compounds.
c. Benefit-per-ton values were estimated for 2015, 2020, 2030, and 2040. For 2021 and 2025, values were interpolated exponentially between 2020 and 2030. For 2060, values were held constant from 2040 values.
d. Note that the benefit-per-ton value for SO_2 is based on the value for stationary sources other than electric generating units; no SO_2 value was estimated for mobile sources. The benefit-per-ton value for VOCs was estimated across all sources.
e. Other than electric generating units (power plants).

4.2 Environmental Consequences

4.2.1 Direct and Indirect Impacts

4.2.1.1 Results of the Analysis

As discussed in Section 4.1, most criteria pollutant emissions from vehicles have been declining since 1970 as a result of EPA's emission regulations under the CAA. EPA projects that these emissions will continue to decline. However, as future trends show, vehicle travel is having a decreasing impact on emissions as a result of stricter EPA standards for vehicle emissions and the chemical composition of fuels, even with additional growth in VMT (Smith 2002). This general trend will continue, to a greater or lesser degree, with implementation of any of the alternative CAFE standards.

The analysis in this section shows that the action alternatives result in different levels of emissions from passenger cars and light trucks when measured against projected trends in the absence of the proposed CAFE standards. These reductions or increases in emissions vary by pollutant, calendar year, and action alternative. The more stringent action alternatives generally would result in greater emission reductions compared to the No Action Alternative.

This section examines the direct and indirect impacts on air quality associated with the action alternatives in Analysis A and Analysis B. Section 4.2.2 examines cumulative air quality impacts of the action alternatives. Appendix A to this EIS provides results for passenger cars and light trucks separately. As explained in Chapter 2:

- Analysis A assesses the impacts of action alternatives where fleetwide fuel economy after MY 2025 will never exceed the level of the MY 2025 standards, in relation to a No Action Alternative under which the light-duty fleet would attain an average fleetwide fuel economy no higher than that required under the agencies' MY 2016 standards established by final rule in April 2010. Tables and figures that depict results for Analysis A include an "A" after the table or figure number.
- Analysis B assesses the impacts of action alternatives assuming ongoing increases beyond the level of the MY 2025 standards in new vehicle fuel economy after MY 2025, in relation to a No Action Alternative that assumes the average fleetwide fuel economy level of light-duty vehicles would continue to increase beyond the level necessary to meet the MY 2016 standards even in the absence of agency action. Tables and figures that depict results for Analysis B include a "B" after the table or figure number.
- The cumulative impacts analysis assesses the impact of fuel economy improvements that result directly or indirectly from the proposed rule in addition to reasonably foreseeable improvements in fuel economy caused by other actors – that is, fuel economy improvements that would result from actions taken by manufacturers without the agencies' action.

Tables 4.2.1-1-A and 4.2.1-1-B through 4.2.1-8-A and 4.2.1-8-B and Figures 4.2.1-1-A and 4.2.1-1-BA through 4.2.1-6-A and 4.2.1-6-B present the projected direct and indirect impacts of the action alternatives on air quality. Following the comparative overview in this section, Sections 4.2.1.2 through 4.2.1.5 describe the results of the analysis of emissions for Alternatives 1 through 4 in greater detail.

4.2.1.1.1 Criteria Pollutants Overview

Tables 4.2.1-1-A and 4.2.1-1-B summarize the total national emissions from passenger cars and light trucks by alternative for each of the criteria pollutants and analysis years for Analysis A and Analysis B, respectively. Figures 4.2.1-1-A and 4.2.1-1-B illustrate this information for 2040, the mid-term forecast year.

Figures 4.2.1-2-A and 4.2.1-2-B summarize the changes over time in total national emissions of criteria pollutants from passenger cars and light trucks for the Preferred Alternative. Figures 4.2.1-2-A and 4.2.1-2-B show a consistent trend among the criteria pollutants. Emissions decline from 2021 to 2025 due to increasingly stringent EPA regulation of tailpipe emissions from vehicles and from reductions in upstream emissions from fuel production, but reach a minimum typically between 2025 and 2040, and increase from 2040 to 2060 due to continuing growth in VMT.

Table 4.2.1-1-A. Nationwide Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Analysis A

Pollutant and Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Carbon monoxide (CO)				
2021	15,584,478	15,612,034	15,617,102	15,582,571
2025	15,835,729	15,916,826	15,901,763	15,649,847
2040	18,859,212	19,172,952	18,903,428	17,160,638
2060	24,544,785	25,040,431	24,676,278	22,215,870
Nitrogen oxides (NO_x)				
2021	1,298,239	1,294,065	1,292,970	1,293,556
2025	1,127,571	1,118,451	1,116,374	1,116,694
2040	1,019,374	1,003,234	1,000,346	962,216
2060	1,313,730	1,295,604	1,293,222	1,239,605
Particulate matter ($PM_{2.5}$)				
2021	57,567	57,013	56,785	55,872
2025	61,838	60,511	59,702	58,141
2040	81,639	78,531	75,499	71,079
2060	106,777	102,850	98,672	92,314
Sulfur dioxide (SO_2)				
2021	154,683	150,846	149,413	145,577
2025	160,300	151,017	147,297	149,268
2040	193,651	170,825	164,239	192,384
2060	251,738	221,360	212,813	251,771
Volatile organic compounds (VOCs)				
2021	1,318,380	1,309,916	1,306,217	1,289,974
2025	1,165,153	1,144,492	1,129,687	1,095,629
2040	960,649	909,859	847,057	740,289
2060	1,208,560	1,142,925	1,056,458	907,711

Table 4.2.1-1-B. Nationwide Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Analysis B

Pollutant and Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Carbon monoxide (CO)				
2021	15,591,975	15,617,633	15,623,706	15,580,150
2025	15,844,684	15,923,075	15,904,803	15,597,117
2040	19,051,746	19,288,497	19,002,492	17,046,122
2060	25,461,054	25,591,703	25,110,535	22,296,504
Nitrogen oxides (NO_x)				
2021	1,297,842	1,293,842	1,292,547	1,293,168
2025	1,126,960	1,117,996	1,116,969	1,119,236
2040	1,004,308	993,913	999,137	968,474
2060	1,267,412	1,263,900	1,277,478	1,233,189
Particulate matter ($PM_{2.5}$)				
2021	57,506	56,994	56,740	55,822
2025	61,752	60,490	59,660	57,989
2040	79,638	77,405	74,542	69,354
2060	100,048	98,534	95,105	87,242
Sulfur dioxide (SO_2)				
2021	154,203	150,646	149,046	145,475
2025	159,637	150,762	146,919	149,624
2040	178,404	161,855	156,028	182,836
2060	196,130	186,052	182,738	214,094
Volatile organic compounds (VOCs)				
2021	1,317,528	1,309,716	1,305,661	1,289,150
2025	1,163,906	1,144,265	1,129,112	1,092,388
2040	930,085	893,929	835,747	718,301
2060	1,104,298	1,079,390	1,011,568	853,254

Figure 4.2.1-1-A. Nationwide Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) for 2040 by Alternative, Analysis A

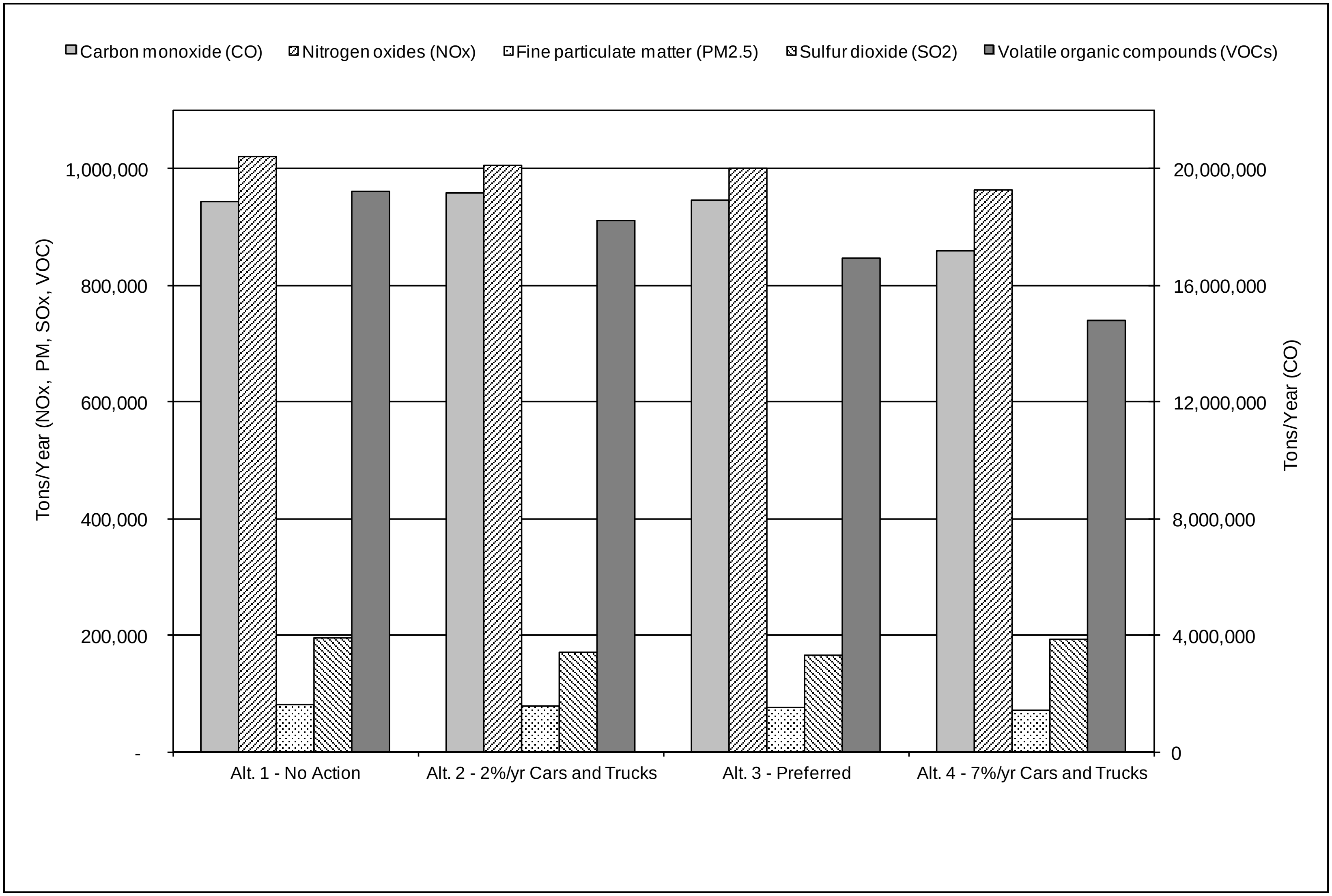


Figure 4.2.1-1-B. Nationwide Criteria Pollutant Emissions from U.S. Passengar Cars and Light Trucks (tons/year) for 2040 Alternative, Analysis B

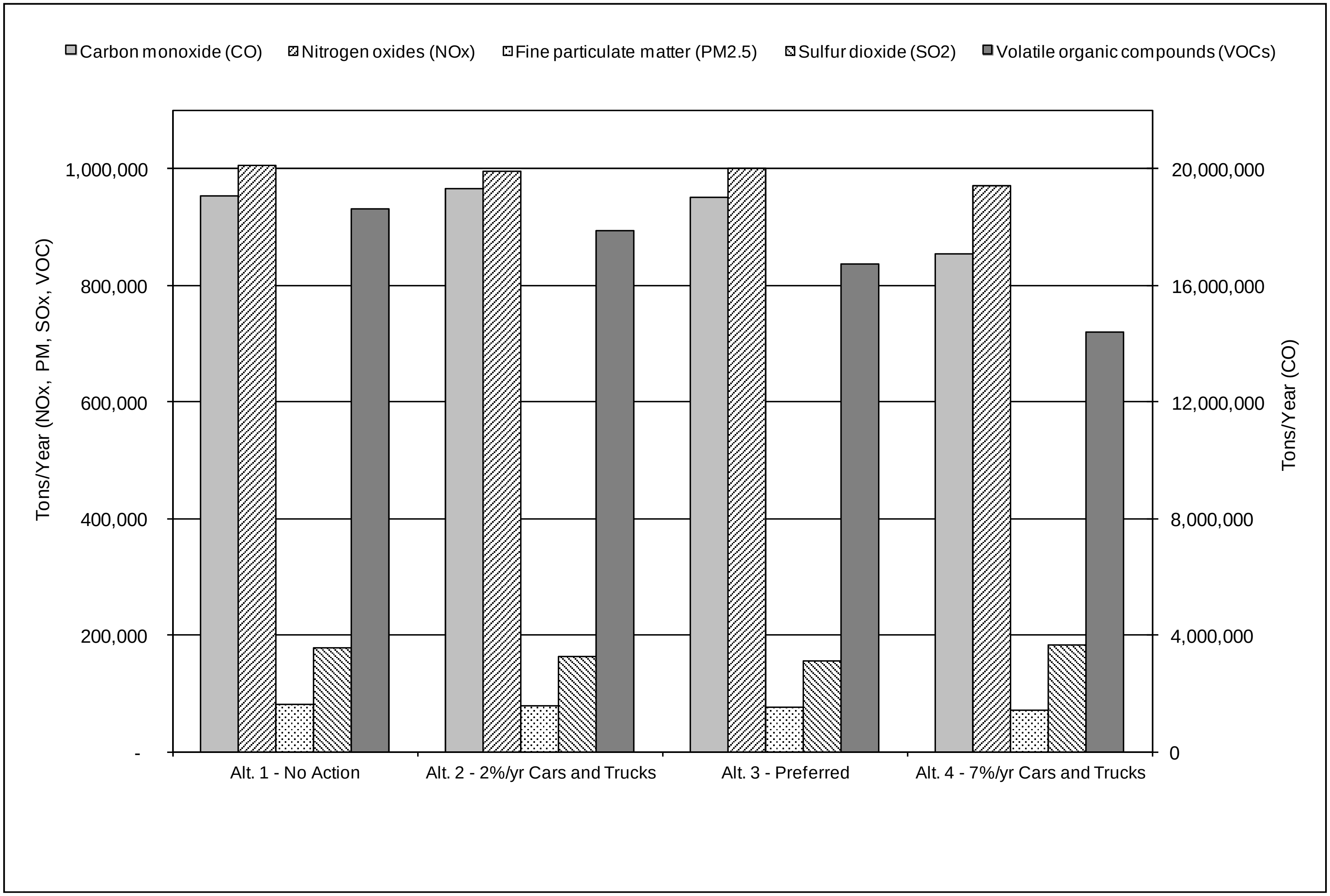


Figure 4.2.1-2-A. Nationwide Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) under the Preferred Alternative by Year, Analysis A

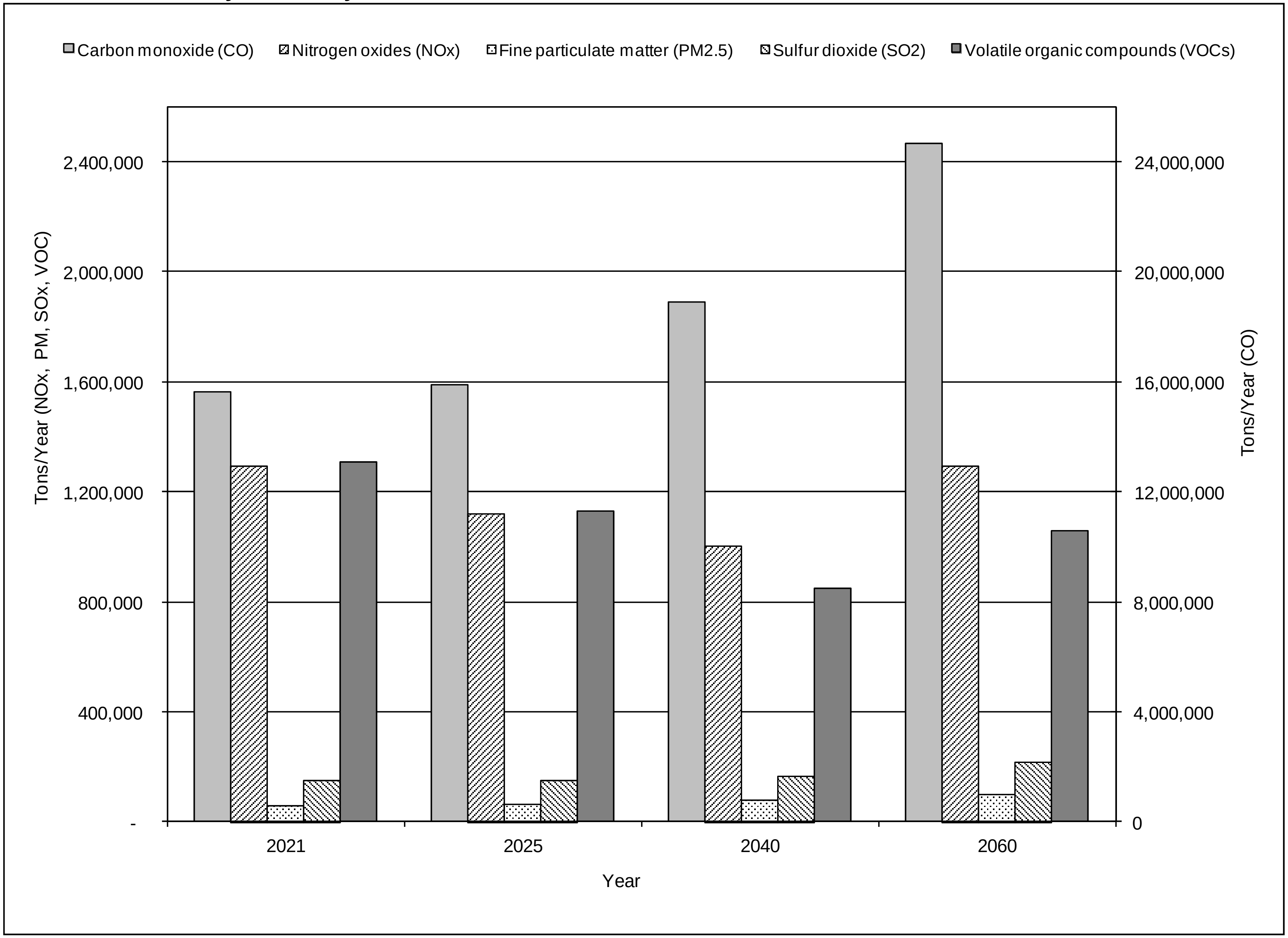
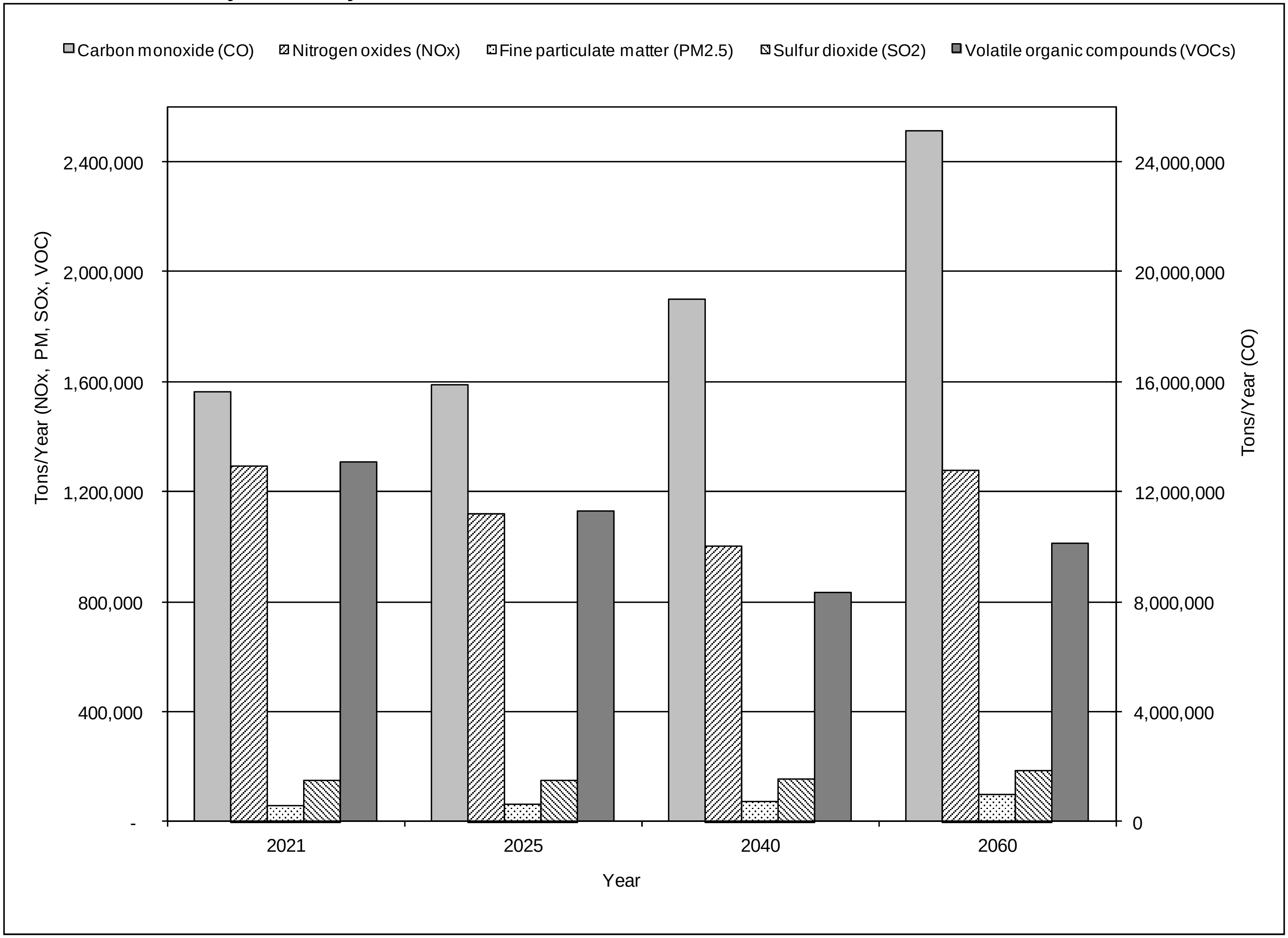


Figure 4.2.1-2-B. Nationwide Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) under the Preferred Alternative by Year, Analysis B



Total emissions are made up of four components consisting of two sources of emissions (downstream and upstream) for each of the two vehicle classes (passenger cars and light trucks) covered by the proposed rule. To show the relationship among these four components for criteria pollutants, tables in Appendix A break down the total emissions of criteria pollutants by component.

Tables 4.2.1-2-A and 4.2.1-2-B list the net change in nationwide criteria pollutant emissions from passenger cars and light trucks for each of the criteria pollutants and analysis years compared to the No Action Alternative. Figures 4.2.1-3-A and 4.2.1-3-B show these changes in percentages for 2040. As a general trend, emissions of each pollutant decrease from Alternatives 2 through 4, as each successive alternative becomes more stringent. However, the magnitudes of the declines are not consistent across all pollutants, reflecting the complex interactions between tailpipe emission rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the proposed standards, upstream emission rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, the proportion of electric vehicles (EVs) in the passenger car and light truck population, and increases in VMT. Under Alternatives 2 and 3, the greatest relative reductions in emissions among the criteria pollutants occur for SO_2 and VOCs, for which emissions decrease by as much as 18 percent by 2060 compared to the No Action Alternative. Emissions of NO_x and $PM_{2.5}$ under Alternatives 2 and 3 decrease by 8 percent or less compared to the No Action Alternative, while CO emissions increase up to 2 percent. Under Alternative 4, the greatest relative reductions in emissions among the criteria pollutants occur for CO, $PM_{2.5}$, and VOCs, for which emissions decrease by as much as 33 percent by 2060. Emissions of NO_x decrease to a lesser extent, by as much as 6 percent by 2060. Emissions of SO_2 are a partial exception to this declining trend, showing increases of up to 8 percent in 2040 and 2060 under Alternative 4 in Analysis B, and a less than 1 percent increase or decrease under Alternative 4 in Analysis A due to the predicted increases in the number of EVs under that alternative. Although electric propulsion produces no downstream emissions, upstream emissions include contributions from the power plants that generate the electricity to recharge EVs, and from the production of the fuel burned in those power plants.

The differences between one action alternative and another in national emissions of criteria air pollutants range from small (less than 1 percent) to large (27 percent), due to the interactions of the multiple factors described above. The small differences are not expected to lead to measurable changes in ambient concentrations of criteria pollutants. The large differences all result in lower emissions and consequently lower ambient air concentrations.

Tables 4.2.1-3-A and 4.2.1-3-B summarize the criteria air pollutant analysis results by nonattainment area. Tables in Appendix B list the emissions changes for each nonattainment area. For CO and $PM_{2.5}$, most nonattainment areas would experience increases in emissions across most years under Alternatives 2 and 3, but decreases in emissions across most years under Alternative 4. For NO_x, most nonattainment areas would experience increases in emissions across all alternatives and years. For SO_2 and VOCs, most nonattainment areas would experience decreases in emissions across all alternatives and years.

Table 4.2.1-2-A. Nationwide Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Analysis A[a,b]

Pollutant and Year	Alternative 1[c] No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Carbon monoxide (CO)				
2021	0	27,556	32,624	-1,907
2025	0	81,097	66,034	-185,882
2040	0	313,741	44,216	-1,698,574
2060	0	495,646	131,493	-2,328,915
Nitrogen oxides (NO_x)				
2021	0	-4,175	-5,269	-4,683
2025	0	-9,120	-11,197	-10,877
2040	0	-16,140	-19,028	-57,158
2060	0	-18,126	-20,508	-74,125
Particulate matter ($PM_{2.5}$)				
2021	0	-554	-782	-1,695
2025	0	-1,326	-2,135	-3,696
2040	0	-3,107	-6,140	-10,559
2060	0	-3,927	-8,105	-14,463
Sulfur dioxide (SO_2)				
2021	0	-3,836	-5,270	-9,105
2025	0	-9,283	-13,003	-11,032
2040	0	-22,826	-29,412	-1,268
2060	0	-30,377	-38,925	33
Volatile organic compounds (VOCs)				
2021	0	-8,464	-12,163	-28,406
2025	0	-20,660	-35,465	-69,524
2040	0	-50,790	-113,592	-220,360
2060	0	-65,634	-152,102	-300,848

a. Emissions changes are rounded to the nearest whole number.
b. Negative emissions changes indicate reductions; positive emissions changes are increases.
c. Emissions changes are shown as zero because the No Action Alternative is the baseline to which emissions under the action alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% decrease compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Table 4.2.1-2-B. Nationwide Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Analysis B[a,b]

Pollutant and Year	Alternative 1[c] No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Carbon monoxide (CO)				
2021	0	25,658	31,731	-11,825
2025	0	78,391	60,119	-247,567
2040	0	236,751	-49,254	-2,005,624
2060	0	130,649	-350,519	-3,164,550
Nitrogen oxides (NO_x)				
2021	0	-4,000	-5,295	-4,674
2025	0	-8,964	-9,991	-7,724
2040	0	-10,395	-5,171	-35,833
2060	0	-3,512	10,066	-34,223
Particulate matter ($PM_{2.5}$)				
2021	0	-512	-766	-1,684
2025	0	-1,262	-2,092	-3,762
2040	0	-2,233	-5,096	-10,284
2060	0	-1,515	-4,943	-12,806
Sulfur dioxide (SO_2)				
2021	0	-3,557	-5,157	-8,728
2025	0	-8,875	-12,717	-10,013
2040	0	-16,549	-22,377	4,432
2060	0	-10,079	-13,393	17,964
Volatile organic compounds (VOCs)				
2021	0	-7,812	-11,867	-28,379
2025	0	-19,641	-34,794	-71,518
2040	0	-36,156	-94,338	-211,784
2060	0	-24,909	-92,730	-251,044

a. Emissions changes are rounded to the nearest whole number.
b. Negative emissions changes indicate reductions; positive emissions changes are increases.
c. Emissions changes are shown as zero because the No Action Alternative is the baseline to which emissions under the action alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% decrease compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Figure 4.2.1-3-A (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative in 2040 Compared to the No Action Alternative, Analysis A

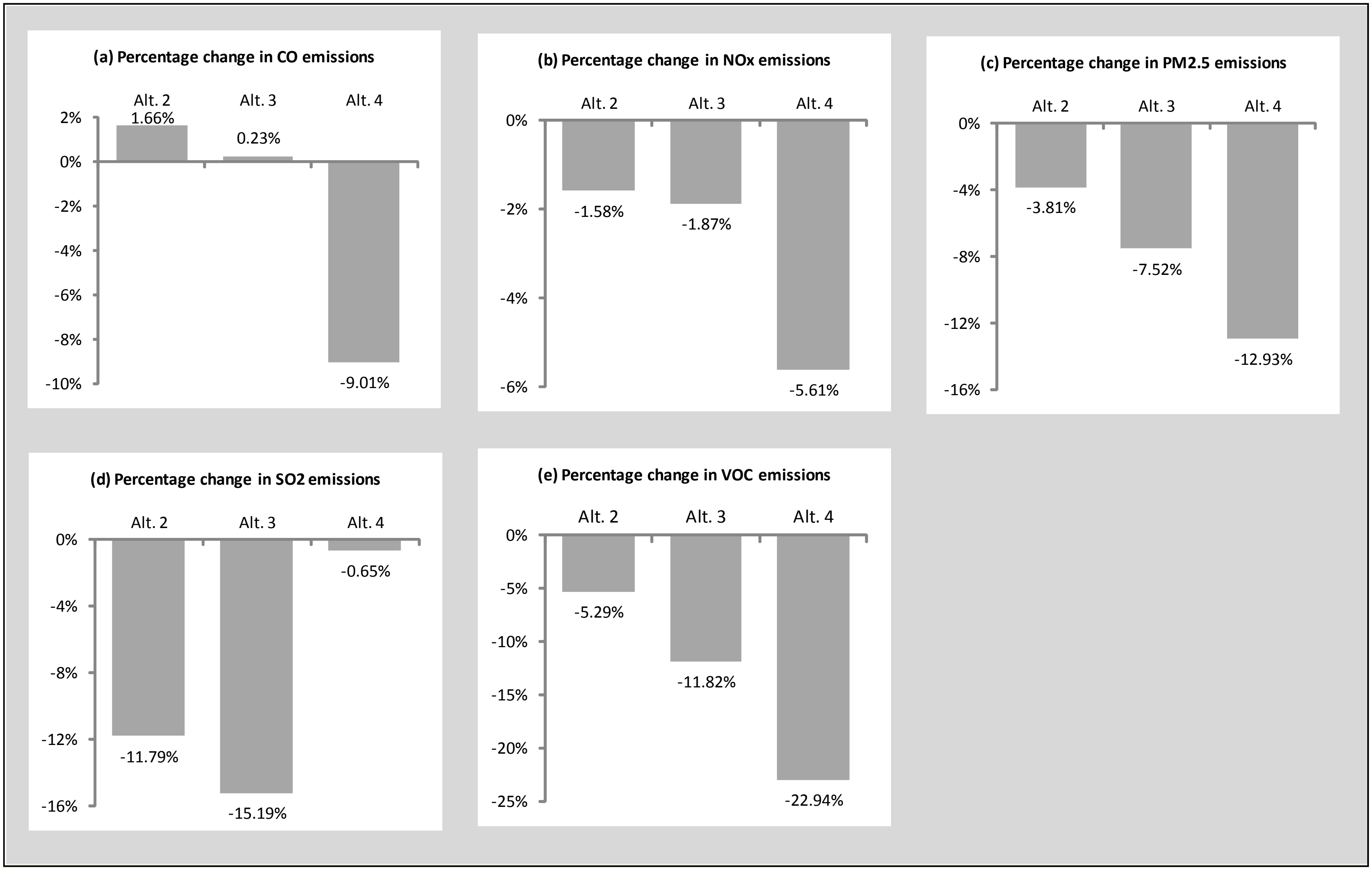


Figure 4.2.1-3-B (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative in 2040 Compared to the No Action Alternative, Analysis B

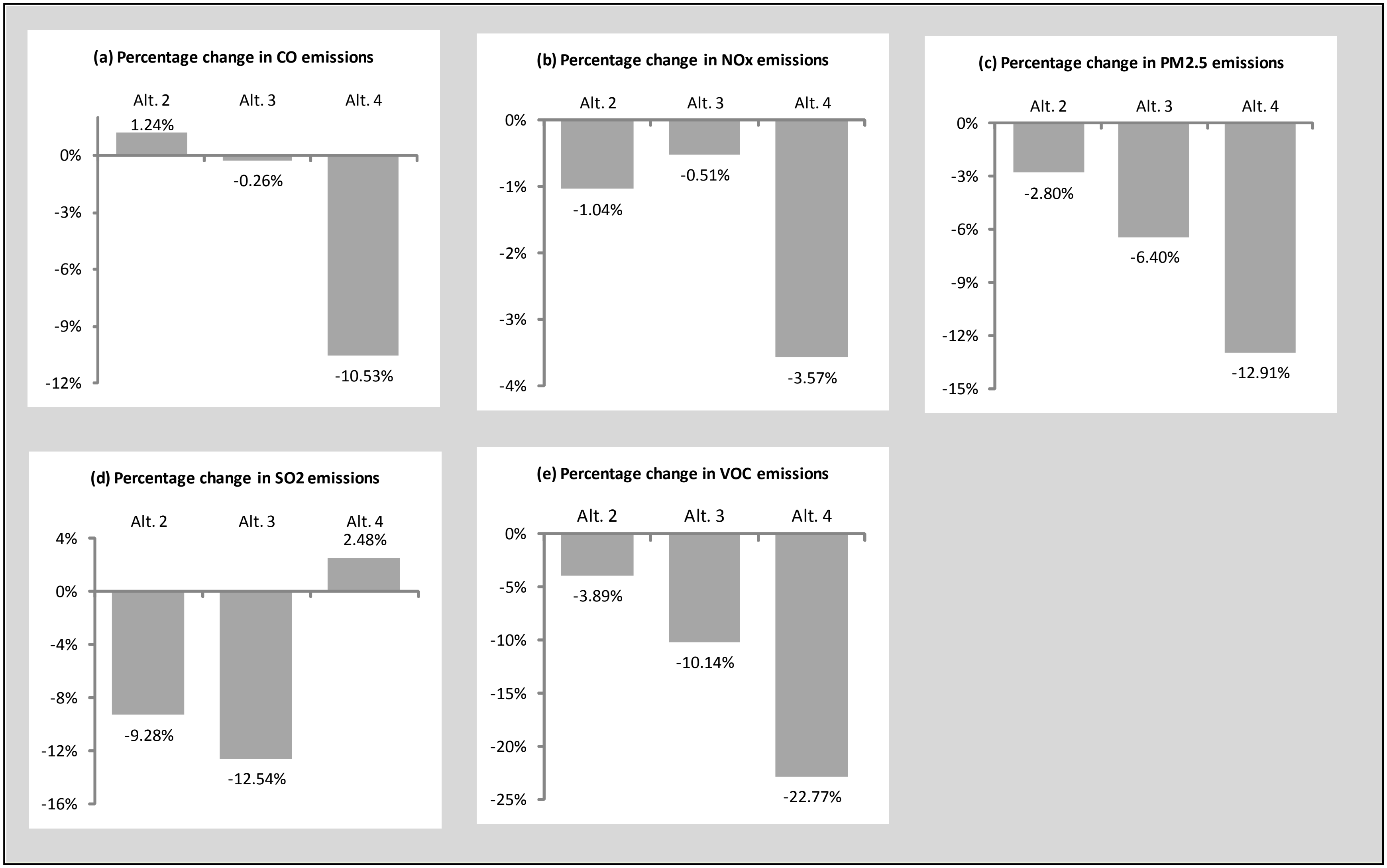


Table 4.2.1-3-A. Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks, Maximum Changes by Nonattainment Area and Alternative, Analysis A[a]

Criteria Pollutant	Maximum Increase/ Decrease	Change (tons/year)	Year	Alternative	Nonattainment Area (Pollutant(s))
Carbon monoxide (CO)	Maximum Increase	24,015	2060	2	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-112,272	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
Nitrogen oxides (NO_x)	Maximum Increase	1,317	2060	3	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)
	Maximum Decrease	-6,610	2060	4	Houston-Galveston-Brazoria, TX (ozone)
Particulate matter ($PM_{2.5}$)	Maximum Increase	29	2060	2	Dallas-Fort Worth, TX (ozone)
	Maximum Decrease	-796	2060	4	Houston-Galveston-Brazoria, TX (ozone)
Sulfur dioxide (SO_2)	Maximum Increase	1,753	2060	4	Beaumont-Port Arthur, TX (ozone)
	Maximum Decrease	-3,526	2060	3	Beaumont-Port Arthur, TX (ozone)
Volatile organic compounds (VOCs)	Maximum Increase	9	2060	2	Riverside County (Coachella Valley), CA (ozone)
	Maximum Decrease	-8,748	2060	4	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)

a. Emissions changes are rounded to the nearest whole number.

Table 4.2.1-3-B. Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks, Maximum Changes by Nonattainment Area and Alternative, Analysis B[a]

Criteria Pollutant	Maximum Increase/ Decrease	Change (tons/year)	Year	Alternative	Nonattainment Area (Pollutant(s))
Carbon monoxide (CO)	Maximum Increase	11,250	2040	2	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-152,663	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
Nitrogen oxides (NO_x)	Maximum Increase	1,332	2060	3	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)
	Maximum Decrease	-3,837	2040	4	Houston-Galveston-Brazoria, TX (ozone)
Particulate matter ($PM_{2.5}$)	Maximum Increase	13	2040	2	Dallas-Fort Worth, TX (ozone)
	Maximum Decrease	-607	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
Sulfur dioxide (SO_2)	Maximum Increase	3,279	2060	4	Beaumont-Port Arthur, TX (ozone)
	Maximum Decrease	-2,014	2040	3	Beaumont-Port Arthur, TX (ozone)
Volatile organic compounds (VOCs)	Maximum Increase	1	2040	2	Riverside County (Coachella Valley), CA (ozone)
	Maximum Decrease	-7,898	2060	4	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)

a. Emissions changes are rounded to the nearest whole number.

4.2.1.1.2 Toxic Air Pollutants Overview

Tables 4.2.1-4-A and 4.2.1-4-B summarize the total national emissions of toxic air pollutants from passenger cars and light trucks by alternative for each of the toxic air pollutants and analysis years. The trends for toxic air pollutant emissions across the alternatives are mixed for the same reasons as for criteria pollutants (*see* Section 4.2.1.1.1). Tables 4.2.1-4-A and 4.2.1-4-B show that emissions of acetaldehyde, acrolein, and formaldehyde generally increase from Alternative 1 to Alternative 4. Emissions of 1,3-butadiene are approximately equivalent for each alternative and year (except for decreases under Alternative 4 in 2040 and 2060). Benzene emissions decrease from Alternative 1 to Alternative 4. DPM emissions generally decrease from Alternative 1 to Alternative 4 (except that in Analysis B, DPM emissions would increase above the no action level under Alternative 4 in 2040 and under Alternatives 3 and 4 in 2060).[18] These trends are accounted for by the extent of technologies assumed to be deployed under the different alternatives to meet the different levels of fuel economy requirements.

Figures 4.2.1-4-A and 4.2.1-4-B show toxic air pollutant emissions for each alternative in 2040, the mid-term forecast year.

[18] As shown in Tables 4.2.4-1-A and 4.2.4-1-B, the predicted DPM emissions under the action alternatives are similar in both Analysis A and Analysis B. However, DPM emissions under the No Action Alternative are lower in Analysis B than in Analysis A, leading to the calculated emissions increases in Analysis B. These differences occur because of the interaction of gains in new vehicle mpg after 2025 with changes in the diesel share of the vehicle population and the diesel share of total fuel usage. The resulting trends in DPM emissions are subject to considerable uncertainty.

Table 4.2.1-4-A. Nationwide Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Analysis A

Pollutant and Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Acetaldehyde				
2021	6,941	6,949	6,955	6,998
2025	6,545	6,573	6,597	6,634
2040	6,888	7,025	7,082	6,673
2060	8,934	9,150	9,231	8,632
Acrolein				
2021	326	326	327	335
2025	301	303	308	323
2040	315	327	357	373
2060	409	426	470	492
Benzene				
2021	31,548	31,524	31,506	31,393
2025	25,569	25,517	25,418	25,035
2040	18,422	18,348	17,543	15,465
2060	23,126	23,090	21,935	18,928
1,3-Butadiene				
2021	3,567	3,570	3,570	3,575
2025	3,089	3,098	3,099	3,082
2040	2,755	2,797	2,753	2,508
2060	3,537	3,604	3,538	3,181
Diesel particulate matter (DPM)				
2021	9,632	9,406	9,339	9,273
2025	9,928	9,393	9,218	9,237
2040	11,955	10,693	10,595	10,743
2060	15,541	13,884	13,868	14,214
Formaldehyde				
2021	7,729	7,731	7,744	7,906
2025	7,118	7,139	7,234	7,557
2040	7,332	7,531	8,172	8,488
2060	9,501	9,811	10,746	11,195

Table 4.2.1-4-B. Nationwide Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Analysis B

Pollutant and Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Acetaldehyde				
2021	6,944	6,950	6,956	6,999
2025	6,548	6,573	6,604	6,646
2040	6,943	7,054	7,140	6,752
2060	9,231	9,319	9,422	8,846
Acrolein				
2021	326	326	327	335
2025	301	303	309	327
2040	317	327	364	398
2060	419	431	486	534
Benzene				
2021	31,551	31,529	31,510	31,390
2025	25,572	25,523	25,417	24,982
2040	18,410	18,363	17,503	15,051
2060	23,315	23,213	21,951	18,366
1,3-Butadiene				
2021	3,568	3,571	3,571	3,575
2025	3,089	3,098	3,100	3,080
2040	2,779	2,811	2,764	2,490
2060	3,659	3,677	3,597	3,187
Diesel particulate matter (DPM)				
2021	9,602	9,389	9,312	9,251
2025	9,887	9,365	9,232	9,352
2040	11,018	10,138	10,468	11,325
2060	12,123	11,723	12,714	14,331
Formaldehyde				
2021	7,731	7,729	7,743	7,907
2025	7,118	7,132	7,251	7,638
2040	7,334	7,509	8,323	9,024
2060	9,605	9,832	11,042	12,094

Figure 4.2.1-4-A. Nationwide Toxic Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) for 2040 by Alternative, Analysis A

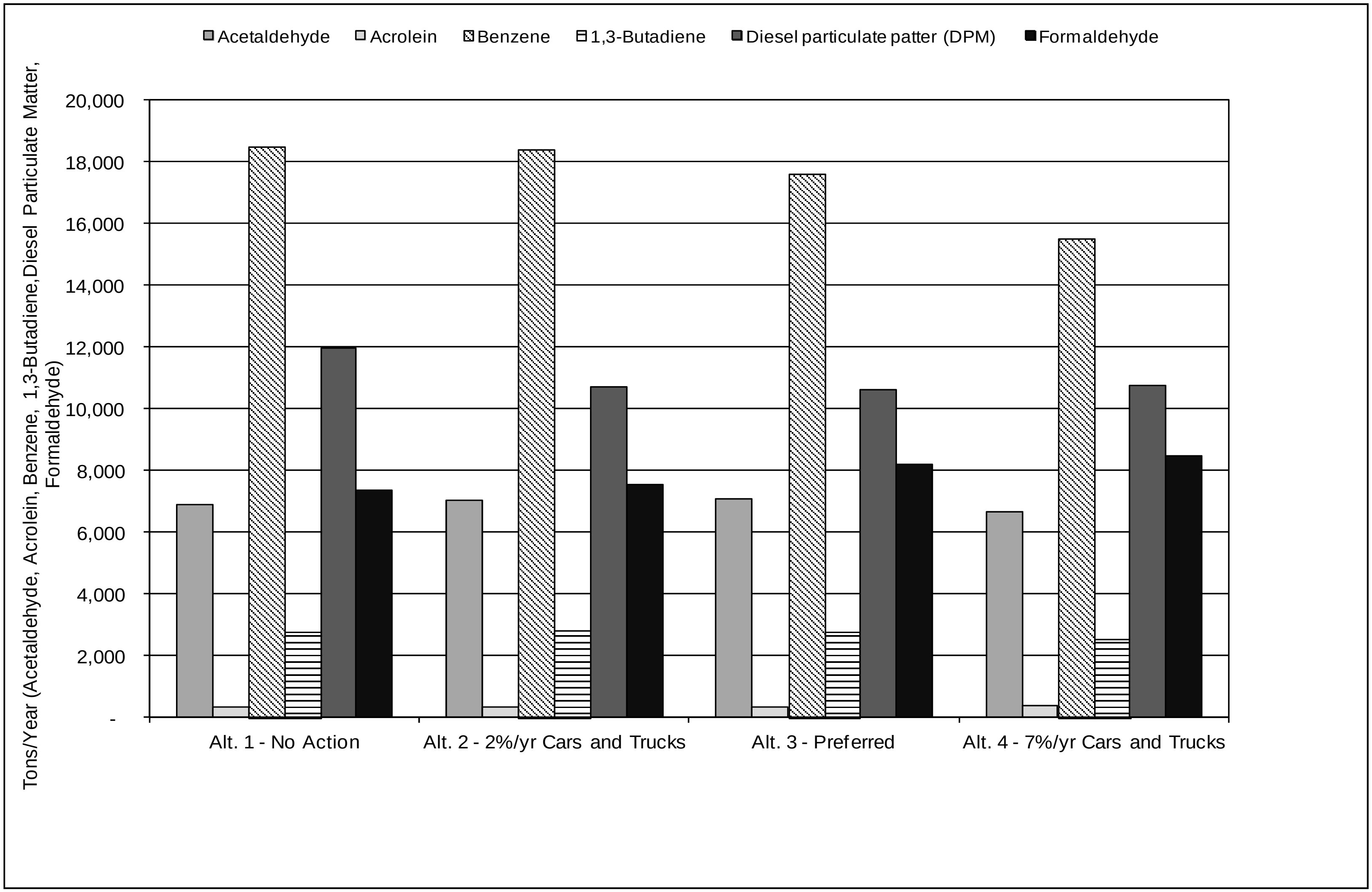
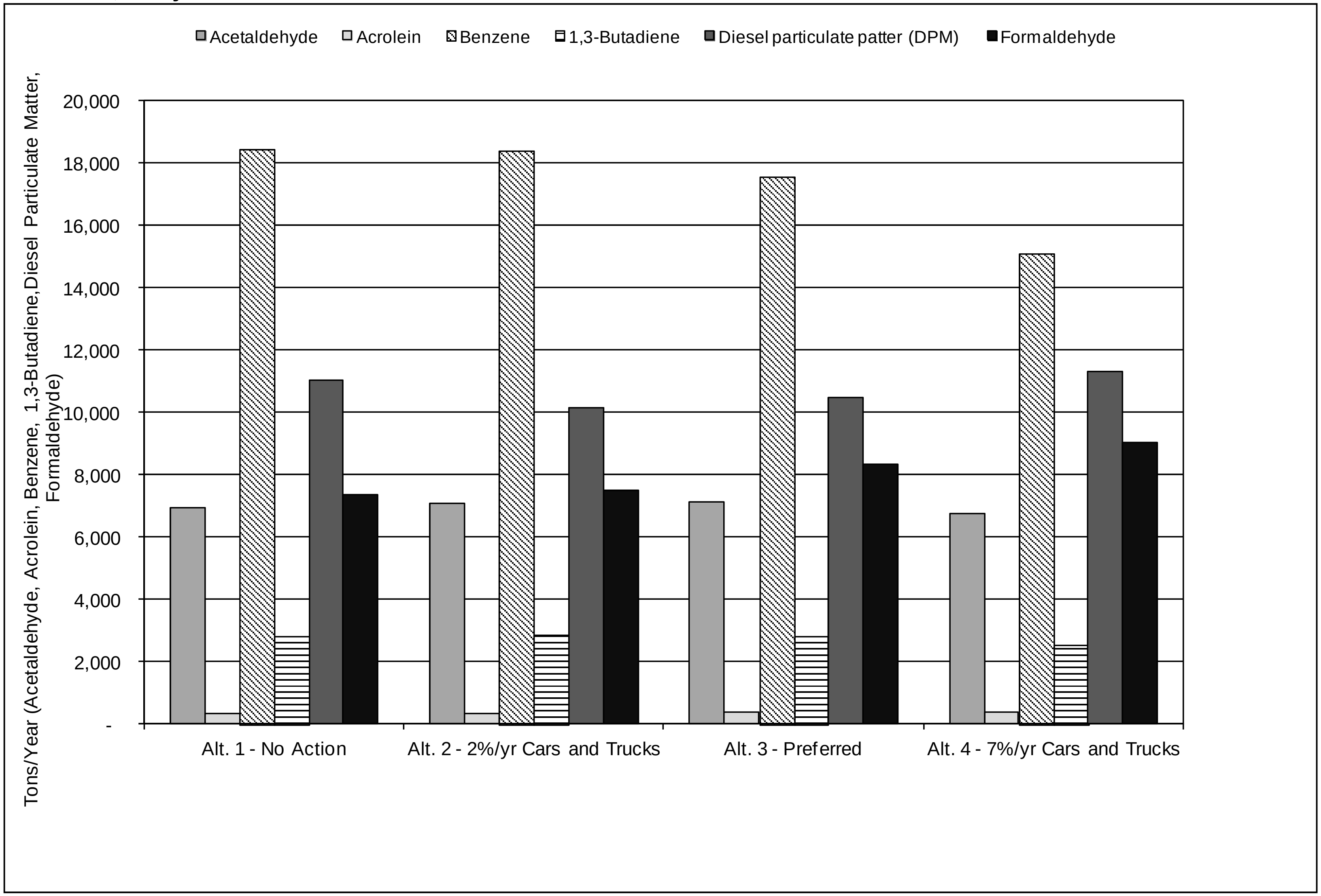


Figure 4.2.1-4-B. Nationwide Toxic Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) for 2040 by Alternative, Analysis B



Figures 4.2.1-5-A and 4.2.1-5-B summarize the changes over time in total national emissions of toxic air pollutants from passenger cars and light trucks under the Preferred Alternative. Figures 4.2.1-5-A and 4.2.1-5-B indicate a consistent trend among the toxic air pollutants. Emissions decline from 2021 to 2025 due to increasingly stringent EPA regulation of emissions from vehicles and from reductions in upstream emissions from fuel production, but reach a minimum typically between 2025 and 2040, and increase from 2040 to 2060 due to continuing growth in VMT.

As with criteria pollutant emissions (*see* Section 4.2.1.1.1), total toxic pollutant emissions are made up of four components, consisting of two sources of emissions (downstream and upstream) for each of the two vehicle classes (passenger cars and light trucks) covered by the proposed rule. To show the relationship among these four components for toxic air pollutants, tables in Appendix A break down the total emissions of toxic air pollutants by component.

Tables 4.2.1-5-A and 4.2.1-5-B list the net change in nationwide emissions from passenger cars and light trucks for each of the toxic air pollutants and analysis years compared to the No Action Alternative. Figures 4.2.1-6-A and 4.2.1-6-B show these changes in percentages for 2040. Tables 4.2.1-5-A and 4.2.1-5-B and Figures 4.2.1-6-A and 4.2.1-6-B show that the magnitude of nationwide emission changes tends to increase from 2021 to 2060, and that emissions under Alternatives 2 and 3 are similar to each other for acetaldehyde, 1,3-butadiene, and DPM (except in 2060), but less similar for acrolein, benzene, and formaldehyde. The magnitude of the emissions changes under Alternative 4 is generally greater than under Alternative 2 and the Preferred Alternative.

Many of the differences between one action alternative and another in national emissions of toxic air pollutants are slight, in the range of 1 percent or less. Consequently, such differences are not expected to lead to measurable changes in ambient concentrations of toxic air pollutants. For such small changes, the impacts of those action alternatives would be essentially equivalent.

Tables 4.2.1-6-A and 4.2.1-6-B summarize the air toxics analysis results by nonattainment area.[19] Tables in Appendix B list the estimated emission changes for each nonattainment area. For acetaldehyde (except under Alternative 4 in 2040 and 2060), acrolein, DPM, and formaldehyde, most nonattainment areas experience increases in emissions across all years and alternatives. For benzene and 1,3-butadiene the results are mixed, with the number of nonattainment areas that experience increases becoming less, and the number that experience decreases becoming greater, under the more stringent alternatives.

[19] EPA has not established NAAQS for airborne toxics. Therefore, none of these areas is nonattainment because of emissions of airborne toxics.

Figure 4.2.1-5-A. Nationwide Toxics Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) under the Preferred Alternative by Year, Analysis A

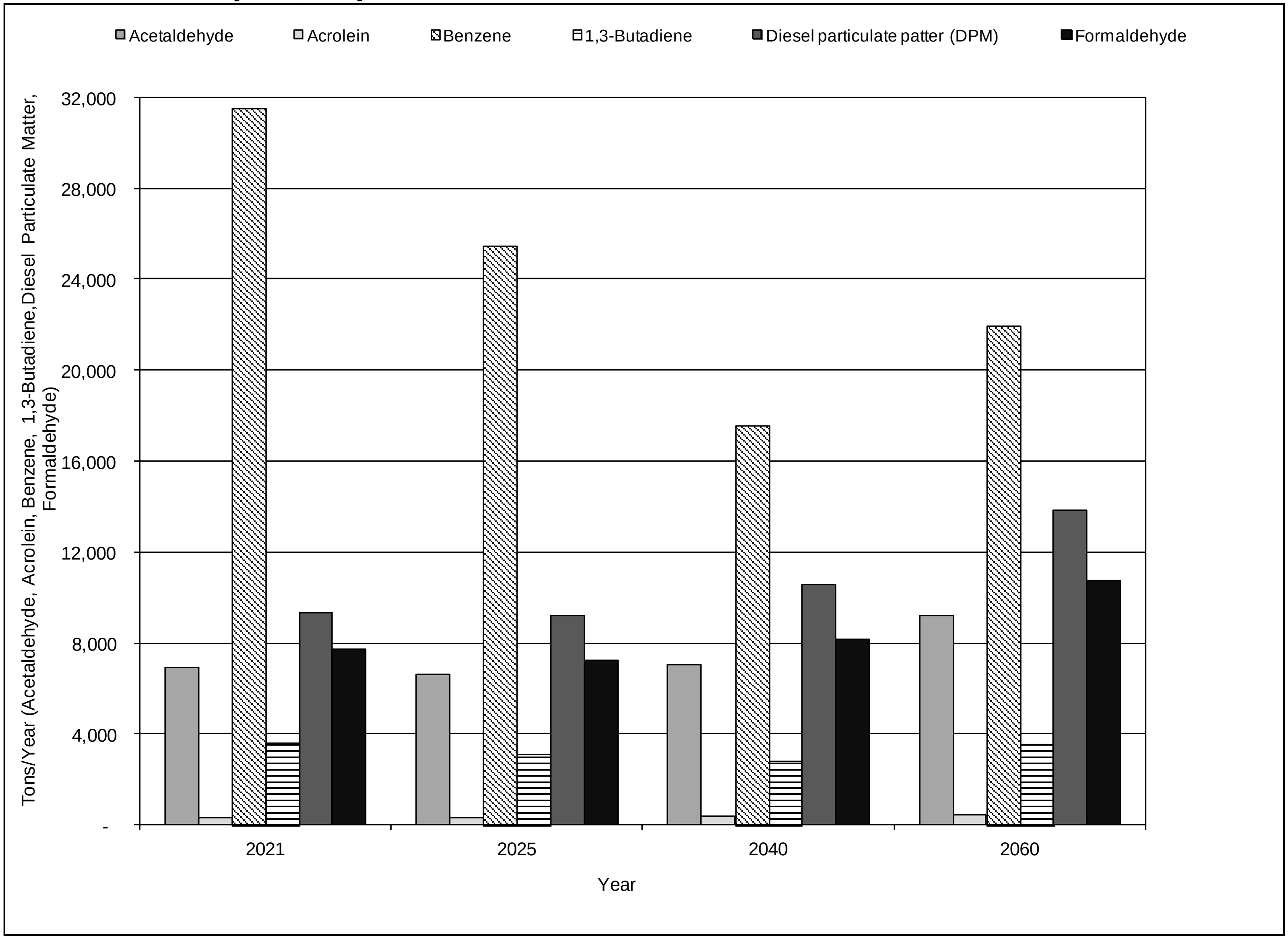


Figure 4.2.1-5-B. Nationwide Toxics Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) under the Preferred Alternative by Year, Analysis B

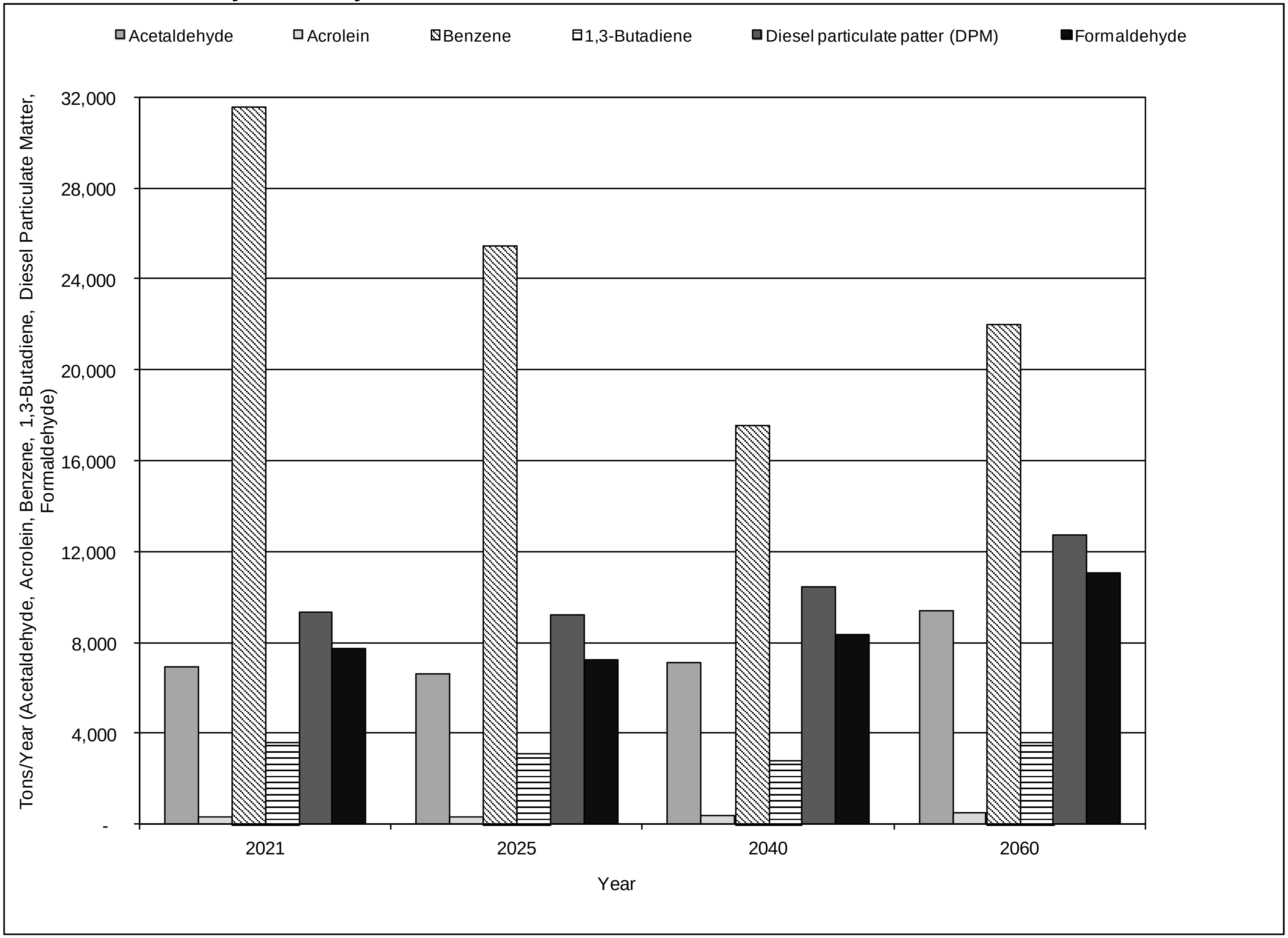


Table 4.2.1-5-A. Nationwide Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Analysis A[a,b]

Pollutant and Year	Alternative 1[c]	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Acetaldehyde				
2021	0	8	13	57
2025	0	28	52	89
2040	0	137	193	-215
2060	0	216	297	-302
Acrolein				
2021	0	1	2	9
2025	0	2	7	22
2040	0	11	42	58
2060	0	17	61	83
Benzene				
2021	0	-24	-42	-155
2025	0	-52	-152	-534
2040	0	-74	-879	-2,956
2060	0	-36	-1,191	-4,198
1,3-Butadiene				
2021	0	3	3	8
2025	0	9	10	-7
2040	0	41	-3	-247
2060	0	67	2	-355
Diesel particulate matter (DPM)				
2021	0	-226	-293	-359
2025	0	-535	-709	-691
2040	0	-1,262	-1,360	-1,212
2060	0	-1,657	-1,673	-1,327
Formaldehyde				
2021	0	2	15	177
2025	0	22	116	439
2040	0	198	839	1,156
2060	0	310	1,246	1,694

a. Emissions changes are rounded to the nearest whole number.
b. Negative emissions changes indicate reductions; positive emissions changes are increases.
c. Emissions changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which emissions under the action alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% decrease compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Table 4.2.1-5-B. Nationwide Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Analysis B[a,b]

Pollutant and Year	Alternative 1[c] No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Acetaldehyde				
2021	0	6	12	55
2025	0	26	56	99
2040	0	111	197	-191
2060	0	89	192	-385
Acrolein				
2021	0	1	2	9
2025	0	2	8	26
2040	0	10	47	80
2060	0	11	66	114
Benzene				
2021	0	-22	-41	-161
2025	0	-49	-155	-589
2040	0	-47	-908	-3,359
2060	0	-103	-1,364	-4,950
1,3-Butadiene				
2021	0	3	3	7
2025	0	9	10	-10
2040	0	32	-14	-289
2060	0	18	-63	-473
Diesel particulate matter (DPM)				
2021	0	-213	-290	-351
2025	0	-521	-655	-535
2040	0	-880	-550	307
2060	0	-401	591	2,208
Formaldehyde				
2021	0	-1	13	176
2025	0	14	133	520
2040	0	175	989	1,690
2060	0	226	1,437	2,489

a. Emissions changes are rounded to the nearest whole number.
b. Negative emissions changes indicate reductions; positive emissions changes are increases.
c. Emissions changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which emissions under the action alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% decrease compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Figure 4.2.1-6-A (a)–(f). Nationwide Percentage Changes in Toxic Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative in 2040 Compared to the No Action Alternative, Analysis A

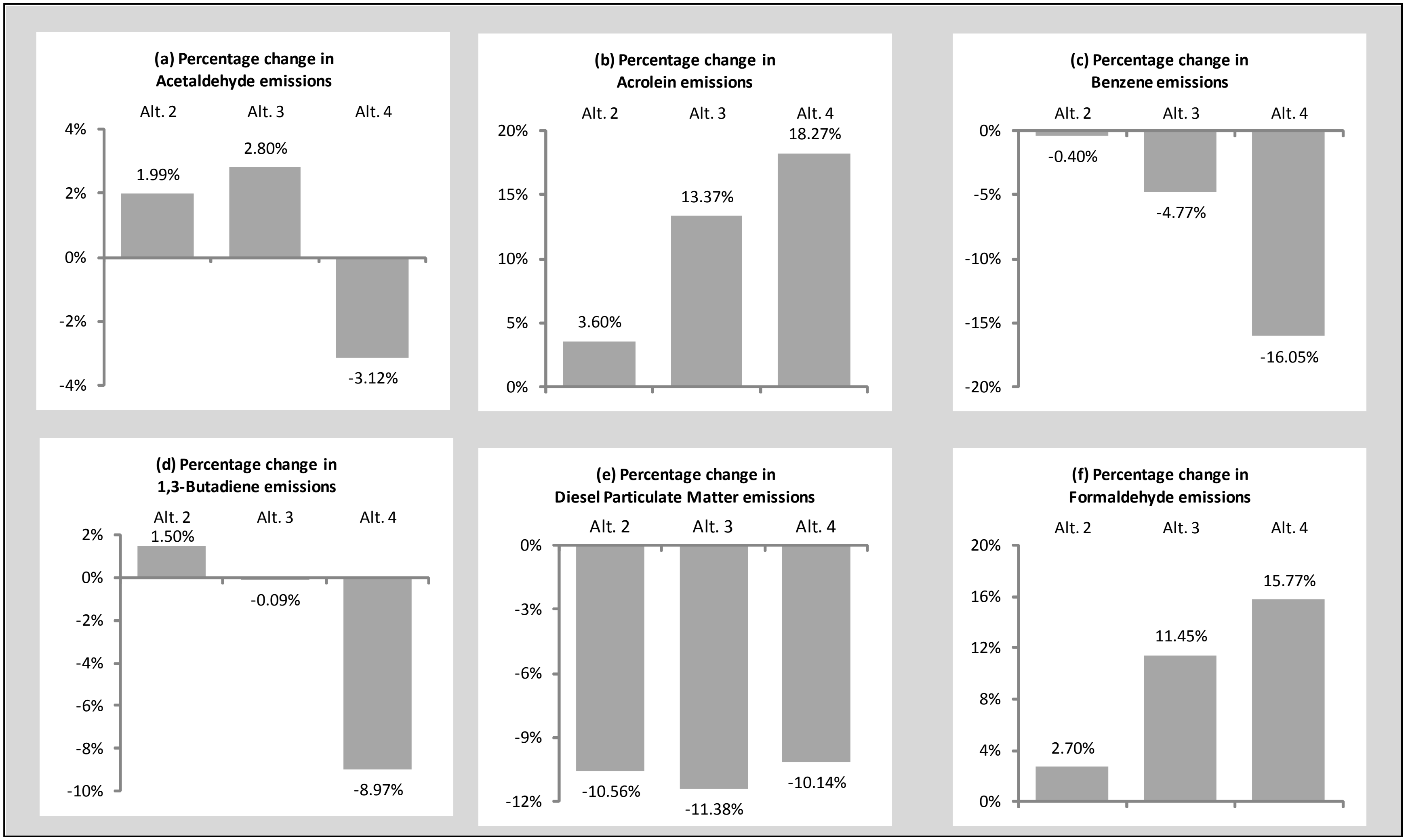


Figure 4.2.1-6-B (a)–(f). Nationwide Percentage Changes in Toxic Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative in 2040 Compared to the No Action Alternative, Analysis B

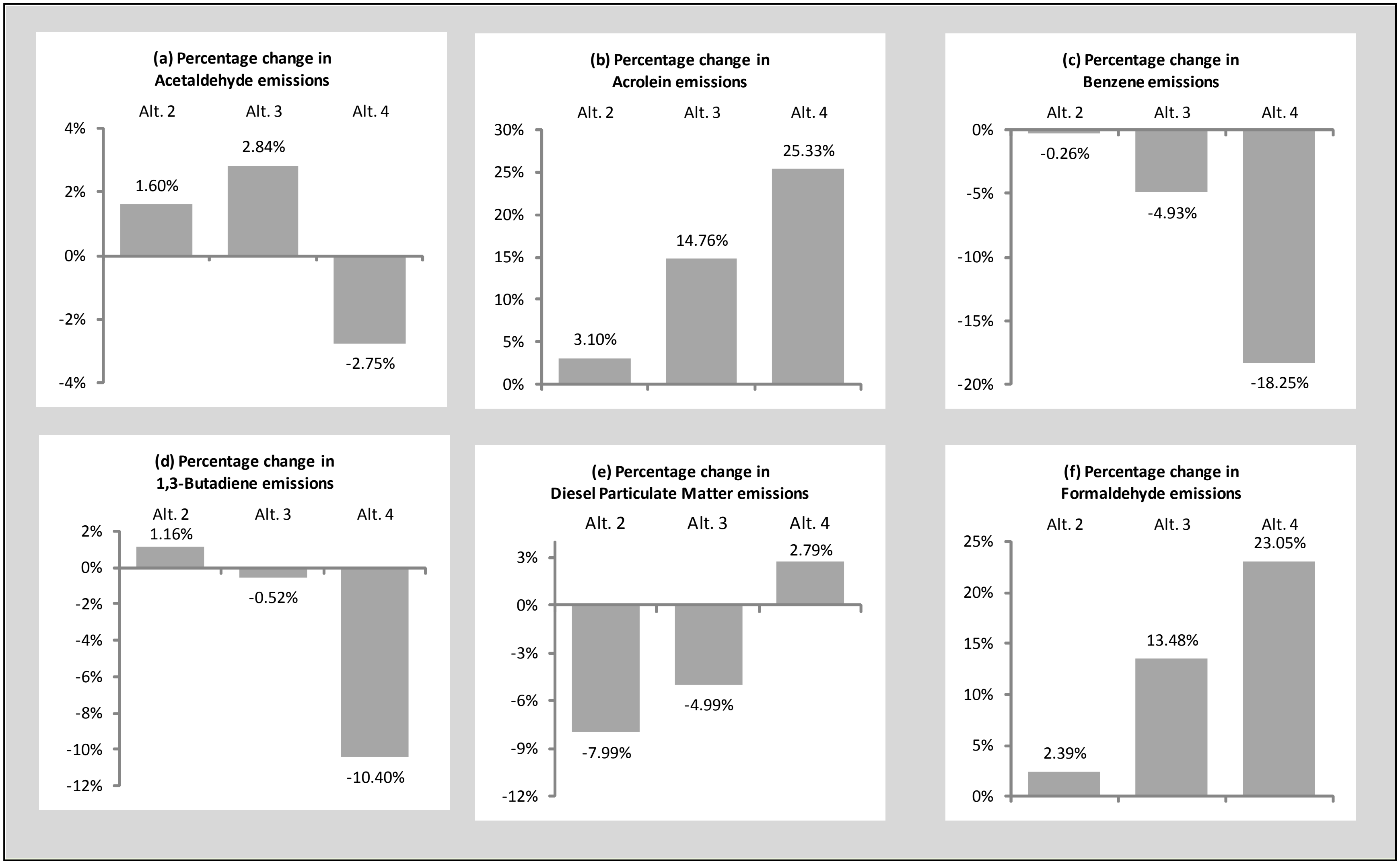


Table 4.2.1-6-A. Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks, Maximum Changes by Nonattainment Area and Alternative, Analysis A[a]

Hazardous Air Pollutant	Maximum Increase/ Decrease	Change (tons/year)	Year	Alternative	Nonattainment Area (Pollutant(s))
Acetaldehyde	Maximum Increase	15	2060	3	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-20	2060	4	Houston-Galveston-Brazoria, TX (ozone)
Acrolein	Maximum Increase	4	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-1	2060	4	Beaumont-Port Arthur, TX (ozone)
Benzene	Maximum Increase	13	2060	2	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-171	2060	4	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)
1,3-Butadiene	Maximum Increase	3	2060	2	Los Angeles South Coast Air Basin, CA (CO, NOx, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-17	2060	4	Los Angeles South Coast Air Basin, CA (CO, NOx, ozone, PM_{10}, $PM_{2.5}$)
Diesel particulate matter (DPM)	Maximum Increase	138	2060	4	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)
	Maximum Decrease	-446	2060	4	Houston-Galveston-Brazoria, TX (ozone)
Formaldehyde	Maximum Increase	97	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, O_3, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-108	2060	4	Houston-Galveston-Brazoria, TX (ozone)

a. Emissions changes are rounded to the nearest whole number.

Table 4.2.1-6-B. Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks, Maximum Changes by Nonattainment Area and Alternative, Analysis B[a]

Hazardous Air Pollutant	Maximum Increase/ Decrease	Change (tons/year)	Year	Alternative	Nonattainment Area (Pollutant(s))
Acetaldehyde	Maximum Increase	10	2040	3	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-18	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
Acrolein	Maximum Increase	6	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-1	2040	4	Beaumont-Port Arthur, TX (ozone)
Benzene	Maximum Increase	5	2040	2	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-209	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
1,3-Butadiene	Maximum Increase	2	2040	2	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-23	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
Diesel particulate matter (DPM)	Maximum Increase	212	2060	4	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)
	Maximum Decrease	-263	2040	4	Houston-Galveston-Brazoria, TX (ozone)
Formaldehyde	Maximum Increase	129	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-62	2040	4	Houston-Galveston-Brazoria, TX (ozone)

a. Emissions changes are rounded to the nearest whole number.

4.2.1.1.3 Health Effects and Monetized Health Benefits Overview

In both Analysis A and Analysis B, adverse health effects would decrease nationwide under each of the action alternatives compared to the No Action Alternative (*see* Tables 4.2.1-7-A and 4.2.1-7-B). Tables 4.2.1-8-A and 4.2.1-8-B list the corresponding monetized health benefits under the action alternatives compared to the No Action Alternative. The reductions in adverse health effects and the monetized health benefits are greater under the more stringent alternatives.

For all health outcomes and years, the health benefits uniformly increase from Alternative 2 (least stringent) to Alternative 4 (most stringent). The benefits also increase steadily from the near future (2021) to later years (2060). These trends are consistent across all health outcomes. Under Alternative 2 in 2021, there is a benefit of up to 3.2 percent in Analysis A and 4.3 percent in Analysis B. Under Alternative 4 in 2060, this benefit increases to a maximum of 12.0 percent (Analysis A) and 10.2 percent (Analysis B). As described in Section 4.1.2.7.2, PM mortality is measured in two ways using the Pope and Laden coefficients. While the number of PM mortalities varies between the two methods, the percent change in mortality across alternatives and years is equal.

The monetized health benefits follow similar trends to the changes in health outcomes. The monetized health benefits of each alternative increase (in percentage terms) from Alternative 2 (least stringent) to Alternative 4 (most stringent) and from the near future (2021) to later years (2060). Monetized health benefits are measured in several ways: first, benefits are measured under the Pope methodology and the Laden methodology (*see* Section 4.1.2.7.2), and second, benefits are measured under a 3 percent discount rate and a 7 percent discount rate. Because the 7 percent discount rate places less present value on future-year benefits than the 3 percent discount rate, the present-year benefit of reductions in 2060 is approximately 10 percent smaller under the 7 percent discount rate than under the 3 percent discount rate. In total, the monetized health benefits in Analysis A range between $210 million and $13 billion, depending on the scenario, alternative, and year. The benefits in Analysis B range from $190 million to $10 billion. All monetary values are measured in year 2011 dollars.

Sections 4.2.1.2 through 4.2.1.5 describe the results of the analysis of emissions for Alternatives 1 through 4 in greater detail. The magnitude of emissions change from one alternative to the next generally increases between Alternative 2 and Alternative 4 consistent with the required greater overall fuel economy.

Health and monetized health benefits increase with each alternative from Alternative 2 through Alternative 4. These health and monetized health benefits are described in greater detail for each alternative in Sections 4.2.1.2 through 4.2.1.5.

Table 4.2.1-7-A. Nationwide Changes in Health Outcomes from Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (cases/year) by Alternative, Analysis A[a,b]

Outcome and Year	Alternative 1[c]	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Mortality (ages 30 and older), Pope et al. (2002)				
2021	0	-32	-44	-85
2025	0	-80	-120	-170
2040	0	-220	-380	-500
2060	0	-290	-500	-680
Mortality (ages 30 and older), Laden et al. (2006)				
2021	0	-81	-110	-220
2025	0	-200	-310	-430
2040	0	-570	-970	-1,300
2060	0	-730	-1,300	-1,700
Chronic bronchitis				
2021	0	-22	-30	-58
2025	0	-53	-81	-110
2040	0	-140	-240	-320
2060	0	-180	-320	-440
Emergency room visits for asthma				
2021	0	-30	-42	-80
2025	0	-75	-110	-150
2040	0	-200	-330	-400
2060	0	-260	-430	-530
Work-loss days				
2021	0	-4,000	-5,600	-11,000
2025	0	-9,800	-15,000	-21,000
2040	0	-24,000	-42,000	-56,000
2060	0	-31,000	-55,000	-75,000

a. Negative changes indicate fewer health impacts; positive changes indicate additional health impacts. Values have been rounded.
b. Negative emissions changes indicate reductions; positive emissions changes are increases.
c. Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% decrease compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Table 4.2.1-7-B. Nationwide Changes in Health Outcomes from Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (cases/year) by Alternative, Analysis B[a,b]

Outcome and Year	Alternative 1[c]	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Mortality (ages 30 and older), Pope et al. (2002)				
2021	0	-29	-43	-83
2025	0	-76	-120	-170
2040	0	-160	-300	-460
2060	0	-100	-250	-520
Mortality (ages 30 and older), Laden et al. (2006)				
2021	0	-75	-110	-210
2025	0	-200	-300	-430
2040	0	-410	-770	-1,200
2060	0	-260	-650	-1,300
Chronic bronchitis				
2021	0	-20	-29	-57
2025	0	-51	-79	-110
2040	0	-100	-190	-300
2060	0	-65	-160	-340
Emergency room visits for asthma				
2021	0	-28	-41	-79
2025	0	-72	-110	-150
2040	0	-140	-260	-350
2060	0	-91	-210	-390
Work-loss days				
2021	0	-3,700	-5,500	-11,000
2025	0	-9,400	-14,000	-21,000
2040	0	-17,000	-33,000	-51,000
2060	0	-11,000	-28,000	-59,000

a. Negative changes indicate fewer health impacts; positive changes indicate additional health impacts. Values have been rounded.
b. Negative emissions changes indicate reductions; positive emissions changes are increases.
c. Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% decrease compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Table 4.2.1-8-A. Nationwide Monetized Health Benefits (U.S. million dollars/year, 2011$) from Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative, Analysis A[a]

Rate and Year	Alternative 1[b]	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
3-Percent Discount Rate				
Benefits-per-ton Assuming Premature Mortality Based on Pope et al. (2002)				
2021	$0	$230	$330	$630
2025	$0	$600	$900	$1,300
2040	$0	$1,700	$3,000	$3,900
2060	$0	$2,200	$3,900	$5,300
Benefits-per-ton Assuming Premature Mortality Based on Laden et al. (2006)				
2021	$0	$570	$800	$1,500
2025	$0	$1,500	$2,200	$3,100
2040	$0	$4,300	$7,300	$9,600
2060	$0	$5,500	$9,600	$13,000
7-Percent Discount Rate				
Benefits-per-ton Assuming Premature Mortality Based on Pope et al. (2002)				
2021	$0	$210	$290	$560
2025	$0	$530	$800	$1,100
2040	$0	$1,600	$2,700	$3,600
2060	$0	$2,000	$3,500	$4,800
Benefits-per-ton Assuming Premature Mortality Based on Laden et al. (2006)				
2021	$0	$510	$710	$1,400
2025	$0	$1,300	$2,000	$2,800
2040	$0	$3,900	$6,600	$8,800
2060	$0	$5,000	$8,700	$12,000

a. Positive changes indicate greater benefits and fewer health impacts; negative changes indicate fewer benefits and additional health impacts. Values have been rounded.
b. Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

≥ 1% decrease	1% or greater decrease in benefits compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease in benefits compared to No Action Alternative
-1% to -10%	1%–10% increase in benefits compared to No Action Alternative
> 10% increase	Greater than 10% increase in benefits compared to No Action Alternative

Table 4.2.1-8-B. Nationwide Monetized Health Benefits (U.S. million dollars/year, 2011$) from Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative, Analysis B[a]

Rate and Year	Alternative 1[b]	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
3-Percent Discount Rate				
Benefits-per-ton Assuming Premature Mortality Based on Pope et al. (2002)				
2021	$0	$220	$320	$620
2025	$0	$570	$880	$1,200
2040	$0	$1,300	$2,400	$3,600
2060	$0	$800	$2,000	$4,100
Benefits-per-ton Assuming Premature Mortality Based on Laden et al. (2006)				
2021	$0	$530	$780	$1,500
2025	$0	$1,400	$2,200	$3,000
2040	$0	$3,100	$5,800	$8,800
2060	$0	$2,000	$4,900	$10,000
7-Percent Discount Rate				
Benefits-per-ton Assuming Premature Mortality Based on Pope et al. (2002)				
2021	$0	$190	$280	$550
2025	$0	$510	$780	$1,100
2040	$0	$1,100	$2,100	$3,300
2060	$0	$730	$1,800	$3,700
Benefits-per-ton Assuming Premature Mortality Based on Laden et al. (2006)				
2021	$0	$470	$690	$1,400
2025	$0	$1,200	$1,900	$2,700
2040	$0	$2,800	$5,300	$8,000
2060	$0	$1,800	$4,400	$9,200

a. Positive changes indicate greater benefits and fewer health impacts; negative changes indicate fewer benefits and additional health impacts. Values have been rounded.
b. Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

≥ 1% decrease	1% or greater decrease in benefits compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease in benefits compared to No Action Alternative
-1% to -10%	1%–10% increase in benefits compared to No Action Alternative
> 10% increase	Greater than 10% increase in benefits compared to No Action Alternative

4.2.1.2 Alternative 1: No Action

4.2.1.2.1 Criteria Pollutants

Under the No Action Alternative for Analysis A, there is no change after 2016 in the forecast for passenger car and light truck fuel economy. The No Action Alternative for Analysis B shows market-based gains in passenger car and light truck fuel economy after 2016 . Current trends in the levels of criteria pollutant emissions from vehicles would continue under the No Action Alternative, with emissions of NO_x and VOCs continuing to decline due to the EPA emission standards (*see* Section 4.1), despite a growth in total VMT from 2021 to 2040, but increasing from 2040 to 2060 due to growth in total VMT during that period (*see* Tables 4.2.1-1-A and 4.2.1-1-B and Figures 4.2.1-1-A and 4.2.1-1-B). Emissions of CO, $PM_{2.5}$ and SO_2 are predicted to increase from 2021 to 2060 because declines due to the EPA emission standards are more than offset by growth in VMT beginning before 2021. The No Action Alternative would not change these trends and therefore would not result in any change in criteria pollutant emissions nationally or in nonattainment areas beyond changes projected to result from future trends in emissions and VMT (*see* Tables 4.2.1-1-A and 4.2.1-1-B).

4.2.1.2.2 Toxic Air Pollutants

EPA regulates toxic air pollutants from motor vehicles through vehicle emission standards and fuel quality standards, as discussed in Section 4.1.1. As with the criteria pollutants, current trends in the levels of toxic air pollutant emissions from vehicles would continue under the No Action Alternative. In both Analysis A and Analysis B, emissions would continue to decline in early years due to the EPA emission standards (*see* Section 4.1.1) despite a growth in total VMT, reaching a minimum in 2025 or 2040 (depending on the pollutant), but increasing in 2060 due to growth in total VMT during that period (*see* Tables 4.2.1-4-A and 4.2.1-4-B and Figures 4.2.1-4-A and 4.2.1-4-B). The No Action Alternative would not change the current CAFE standards and therefore would not result in any change in toxic air pollutant emissions throughout the United States beyond projected trends shown for the No Action Alternative in Tables 4.2.1-4-A and 4.2.1-4-B.

Emissions under the No Action Alternative are generally less than those under each of the action alternatives for acrolein and formaldehyde, but greater for benzene and DPM. Results are mixed for 1,3-butadiene and acetaldehyde. For both Analysis A and Analysis B, changes in emissions are greatest in 2060, in which emissions under the action alternatives range up to 27 percent greater or smaller than under the No Action Alternative.

4.2.1.2.3 Health Outcomes and Monetized Benefits

Under the No Action Alternative, current trends in the levels of criteria pollutant and toxic air pollutant emissions from vehicles would continue, with emissions of most criteria pollutants decreasing initially and then increasing to 2060 due to growth in total VMT, which more than offsets reductions due to the EPA vehicle emission standards (*see* Section 4.1.1). In both Analysis A and Analysis B, the human health-related impacts expected under current trends would continue (*see* Tables 4.2.1-7-A, 4.2.1-7-B, 4.2.1-8-A, and 4.2.1-8-B). The No Action Alternative would not result in any other increase or decrease in human health impacts throughout the United States.

4.2.1.3 Alternative 2: 2 Percent per Year Increase in Fuel Economy

4.2.1.3.1 Criteria Pollutants

Tables 4.2.1-2-A and 4.2.1-2-B show the changes in nationwide emissions of criteria pollutants under Alternative 2 compared to the No Action Alternative and the other action alternatives. Figures 4.2.1-3-A and 4.2.1-3-B show these changes in percentages for 2040. Under Alternative 2, nationwide emissions of $PM_{2.5}$, NO_x, SO_2, and VOCs compared to the No Action Alternative would be reduced. Alternative 2 is the least stringent of all the action alternatives, and the reductions under Alternative 2 are smaller than those under the other action alternatives. Emissions of CO increase compared to the No Action Alternative in all years because declines due to EPA's emission standards and greater fuel economy are more than offset by growth in VMT.

Under Alternative 2, all nonattainment areas would experience reductions in emissions of SO_2, and most would experience reductions in emissions of VOCs compared to the No Action Alternative. Most nonattainment areas would experience slight increases in CO, NO_x, and $PM_{2.5}$ emissions. These increases are due to the rebound effect, which more than offsets emission reductions from decreased fuel usage. Tables in Appendix B list the emission changes for each nonattainment area.

4.2.1.3.2 Toxic Air Pollutants

Tables 4.2.1-5-A and 4.2.1-5-B show the changes in nationwide emissions of toxic air pollutants under Alternative 2 compared to the No Action Alternative and the other action alternatives. Figures 4.2.1-6-A and 4.2.1-6-B show these changes in percentages for 2040. Compared to the No Action Alternative, Alternative 2 would result in reduced emissions of benzene and DPM, increased emissions of acetaldehyde, acrolein, and formaldehyde (except in 2021 in Analysis B), and approximately equivalent emissions of 1,3-butadiene for all analysis years. Compared to Alternative 2, emissions under the other action alternatives would be generally higher for acetaldehyde (except for Alternative 4 in 2040 and 2060), acrolein, and formaldehyde, and generally lower for benzene, 1,3-butadiene, and DPM (except in 2040 and 2060).

At the national level, emissions of all toxic air pollutants could increase because the increases in vehicle emissions due to the rebound effect more than offset reductions in upstream emissions of toxic air pollutants due to improved fuel economy and the resulting decline in the volume of fuel refined and distributed. However, the increases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 2, most nonattainment areas would experience net increases in emissions of most toxic air pollutants in all of the analysis years (*see* Appendix B).

4.2.1.3.3 Health Outcomes and Monetized Benefits

In both Analysis A and Analysis B, adverse health effects nationwide would be reduced compared to the No Action Alternative (*see* Tables 4.2.1-7-A and 4.2.1-7-B). These health benefits increase greatly from 2021 to 2060. As shown in Tables 4.2.1-8-A and 4.2.1-8-B, the monetized health benefits under Alternative 2 range from approximately $190 million to $5.5 billion across Analyses A and B. These monetized health benefits are the smallest of all the action alternatives.

4.2.1.4 Alternative 3: Preferred

4.2.1.4.1 Criteria Pollutants

Tables 4.2.1-2-A and 4.2.1-2-B show the changes in nationwide emissions of criteria pollutants under Alternative 3 compared to the No Action Alternative and the other action alternatives. Figures 4.2.1-3-A and 4.2.1-3-B show these changes in percentages for 2040. Figures 4.2.1-2-A and 4.2.1-2-B show criteria pollutant emissions under Alternative 3 by year. Under this alternative, emissions of all pollutants except CO are generally reduced compared to the No Action Alternative. CO emissions are increased compared to the No Action Alternative (except in 2040 and 2060 under Analysis B) because declines due to the EPA emission standards and greater fuel economy are more than offset by growth in VMT. This alternative generally reduces emissions more than Alternative 2, but less than the more stringent Alternative 4.

Under Alternative 3, all nonattainment areas would experience reductions in emissions of SO_2 and VOCs for all years, and for $PM_{2.5}$ and CO (in Analysis B) in 2040 and 2060. Most nonattainment areas would experience increases in emissions of CO and $PM_{2.5}$ in 2021 and 2025 and NO_x in all years. The increases in CO and $PM_{2.5}$ emissions occur because declines due to the EPA emission standards and greater fuel economy are more than offset by growth in VMT. The increases in NO_x emissions are due to increases in the diesel vehicle share of total VMT. Tables in Appendix B list the emission changes for each nonattainment area.

4.2.1.4.2 Toxic Air Pollutants

Tables 4.2.1-5-A and 4.2.1-5-B show the changes in nationwide emissions of toxic air pollutants under Alternative 3 compared to the No Action Alternative and the other action alternatives. Figures 4.2.1-5-A and 4.2.1-5-B show toxic pollutant emissions under Alternative 3 by year. Figures 4.2.1-6-A and 4.2.1-6-B shows these changes in percentage terms for 2040. Compared to the No Action Alternative, Alternative 3 would generally result in reduced emissions of benzene and DPM (except in 2060 in Analysis B), increased emissions of acetaldehyde, acrolein and formaldehyde, and approximately equivalent emissions of 1,3-butadiene, for all analysis years. Emissions under Alternative 3 are greater than under Alternative 2 for acetaldehyde, acrolein, and formaldehyde, but lower for benzene. Results are mixed for 1,3-butadiene and DPM. Compared to Alternative 4, emissions under Alternative 3 would be generally lower for acetaldehyde (in 2021 and 2025), acrolein, 1,3-butadiene (in 2021), DPM (except in 2021) and formaldehyde; but generally higher for benzene, acetaldehyde (except in 2021 and 2025), 1,3-butadiene (except in 2021), and DPM (in 2021).

At the national level, emissions of most toxic air pollutants could increase because the increases in vehicle emissions due to the rebound effect more than offset reductions in upstream emissions of toxic air pollutants due to improved fuel economy and the resulting decline in the volume of fuel refined and distributed. However, as with less stringent alternatives, the reductions in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 3, most nonattainment areas would experience net increases in emissions of all toxic air pollutants in all of the analysis years (*see* Appendix B), with the exception of benzene emissions, which would decrease in most nonattainment areas in 2025, 2040, and 2060, and 1,3-butadiene emissions, which would decrease in all nonattainment areas in 2040 and 2060 in Analysis B.

4.2.1.4.3 Health Outcomes and Monetized Benefits

In both Analysis A and Analysis B, reductions in adverse health effects would occur nationwide under Alternative 3 compared to the No Action Alternative (*see* Tables 4.2.1-7-A and 4.2.1-7-B). These health benefits increase greatly from 2021 to 2060. As shown in Tables 4.2.1-8-A and 4.2.1-8-B, the monetized health benefits under Alternative 3 range from approximately $280 million to $9.6 billion across Analyses A and B. These benefits are greater than those under Alternative 2 for all health outcomes and years, but less than those under Alternative 4.

4.2.1.5 Alternative 4: 7 Percent per Year Increase in Fuel Economy

4.2.1.5.1 Criteria Pollutants

Tables 4.2.1-2-A and 4.2.1-2-B the changes in nationwide emissions of criteria pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figures 4.2.1-3-A and 4.2.1-3-B show these changes in percentages for 2040. Under Alternative 4, nationwide emissions of all criteria pollutants compared to the No Action Alternative would be reduced because of EPA emission standards and greater fuel economy, despite an increase in VMT (except for SO_2 in 2040 and 2060). These reductions would be greater than under any other alternative (except for NO_x in 2021 and 2025, and SO_2 in 2025, 2040, and 2060). The increases in NO_x and SO_2 emissions are due to increases in the diesel and EV shares of total VMT.

Under Alternative 4, all nonattainment areas would experience reductions in emissions $PM_{2.5}$, and VOCs for all years, CO in 2025 through 2060, and SO_2 in 2021 and 2025. Most nonattainment areas would experience increases in NO_x emissions in all years, while a few nonattainment areas would see larger decreases in these years. SO_2 emissions would decrease in most nonattainment areas in 2040 and 2060, while a few nonattainment areas would experience larger increases in these years. Results for CO emissions in 2021 are mixed. The increases in NO_x and SO_2 emissions in some nonattainment areas are due to the EPA emission standards and greater fuel economy being more than offset by growth in VMT. Tables in Appendix B list the emission changes for each nonattainment area.

4.2.1.5.2 Toxic Air Pollutants

Tables 4.2.1-5-A and 4.2.1-5-B show the changes in nationwide emissions of toxic air pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figures 4.2.1-6-A and 4.2.1-6-B shows these changes in percentages for 2040. Compared to the No Action Alternative, Alternative 4 would result in reduced emissions of acetaldehyde (in 2040 and 2060), benzene, 1,3-butadiene (except in 2021), and DPM (except in 2040 and 2060 in Analysis B), and in increased emissions of acrolein and formaldehyde. Under Alternative 4, emissions of acetaldehyde (in 2040 and 2060), benzene, 1,3-butadiene (except in 2021), and DPM (in 2021) are less than under all other action alternatives.

At the national level, as with the less stringent alternatives, emissions of most toxic air pollutants could increase for the reasons described above (*see* Section 4.2.1.4.2). Under Alternative 4, nonattainment areas would experience net increases in emissions of acrolein, DPM, and formaldehyde in all of the analysis years (*see* Appendix B). Benzene emissions would decrease in all nonattainment areas in all years. 1,3-butadiene emissions would decrease in all nonattainment areas in all years except 2021. Acetaldehyde emissions would decrease in all nonattainment areas in 2040 and 2060 and increase in most nonattainment areas in 2021 and 2025.

4.2.1.5.3 Health Outcomes and Monetized Benefits

In both Analysis A and Analysis B, reductions in adverse health effects nationwide would occur under Alternative 4 compared to the No Action Alternative (*see* Tables 4.2.1-7-A and 4.2.1-7-B). These health benefits increase greatly from 2021 to 2060. As shown in Tables 4.2.1-8-A and 4.2.1-8-B, the monetized health benefits under Alternative 4 range from approximately $550 million to $13 billion. The health and monetized health benefits under Alternative 4 are greater than those of all other alternatives.

4.2.2 Cumulative Impacts

4.2.2.1 Results of the Analysis

As discussed in Section 4.1, most criteria pollutant emissions from vehicles have been declining since 1970 as a result of EPA's emission regulations under the CAA. EPA projects that these emissions will continue to decline. However, as future trends show, vehicle travel is having a decreasing impact on emissions as a result of stricter EPA standards for vehicle emissions and the chemical composition of fuels, even with additional growth in VMT (Smith 2002). This general trend will continue, to a greater or lesser degree, with implementation of any of the alternative CAFE standards.

The analysis in this section shows that the action alternatives result in different levels of emissions from passenger cars and light trucks when measured against projected trends in the absence of the proposed CAFE standards. These reductions or increases in emissions vary by pollutant, calendar year, and action alternative. The more stringent action alternatives generally would result in greater emission reductions compared to the No Action Alternative. Tables 4.2.2-1 through 4.2.2-8 and Figures 4.2.2-1 through 4.2.2-6 present the results of the air quality cumulative impacts analysis. Following the comparative overview in this section, Sections 4.2.2.2 through 4.2.2.8 describe the results of the analysis of emissions for Alternatives 1 through 4 in greater detail.

4.2.2.1.1 Criteria Pollutants Overview

Table 4.2.2-1 summarizes the total national emissions from passenger cars and light trucks by alternative for each of the criteria pollutants and analysis years. Figure 4.2.2-1 illustrates this information for 2040, the mid-term forecast year.

Figure 4.2.2-2 summarizes the changes over time in total national emissions of criteria pollutants from passenger cars and light trucks under the Preferred Alternative. Figure 4.2.2-2 shows mixed trends for the criteria pollutants. Emissions of NO_x and VOCs decline from 2021 to 2025 due to increasingly stringent EPA regulation of tailpipe emissions from vehicles and from reductions in upstream emissions from fuel production, but reach a minimum typically between 2025 and 2040, and increase from 2040 to 2060 due to continuing growth in VMT. Emissions of CO, $PM_{2.5}$, and SO_2 increase steadily from 2021 to 2060 because, for these pollutants, the reductions from EPA regulation of tailpipe emissions and reductions in upstream emissions from fuel production are more than offset by continuing growth in VMT.

Total emissions are made up of four components, consisting of two sources of emissions (downstream and upstream) for each of the two vehicle classes (passenger cars and light trucks) covered by the proposed rule. To show the relationship among these four components for criteria pollutants, tables in Appendix A break down the total emissions of criteria pollutants by component.

Table 4.2.2-1. Nationwide Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Cumulative Impacts

Pollutant and Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Carbon monoxide (CO)				
2021	15,584,478	15,617,633	15,623,706	15,580,150
2025	15,835,729	15,923,075	15,904,803	15,597,117
2040	18,859,212	19,288,497	19,002,492	17,046,122
2060	24,544,785	25,591,703	25,110,535	22,296,504
Nitrogen oxides (NO_x)				
2021	1,298,239	1,293,842	1,292,547	1,293,168
2025	1,127,571	1,117,996	1,116,969	1,119,236
2040	1,019,374	993,913	999,137	968,474
2060	1,313,730	1,263,900	1,277,478	1,233,189
Particulate matter ($PM_{2.5}$)				
2021	57,567	56,994	56,740	55,822
2025	61,838	60,490	59,660	57,989
2040	81,639	77,405	74,542	69,354
2060	106,777	98,534	95,105	87,242
Sulfur dioxide (SO_2)				
2021	154,683	150,646	149,046	145,475
2025	160,300	150,762	146,919	149,624
2040	193,651	161,855	156,028	182,836
2060	251,738	186,052	182,738	214,094
Volatile organic compounds (VOCs)				
2021	1,318,380	1,309,716	1,305,661	1,289,150
2025	1,165,153	1,144,265	1,129,112	1,092,388
2040	960,649	893,929	835,747	718,301
2060	1,208,560	1,079,390	1,011,568	853,254

Figure 4.2.2-1. Nationwide Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) for 2040 by Alternative, Cumulative Impacts

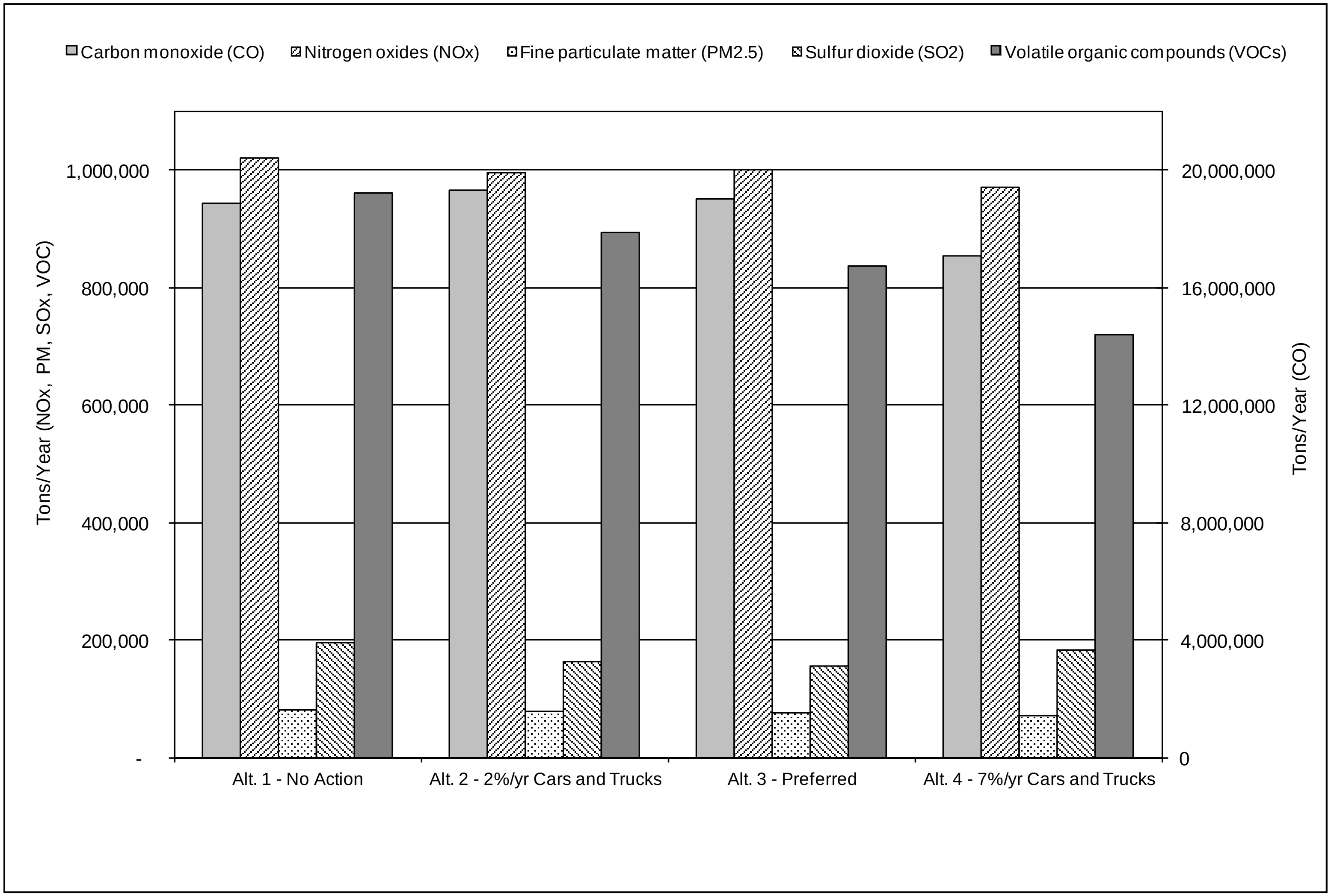


Figure 4.2.2-2. Nationwide Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) under the Preferred Alternative by Year, Cumulative Impacts

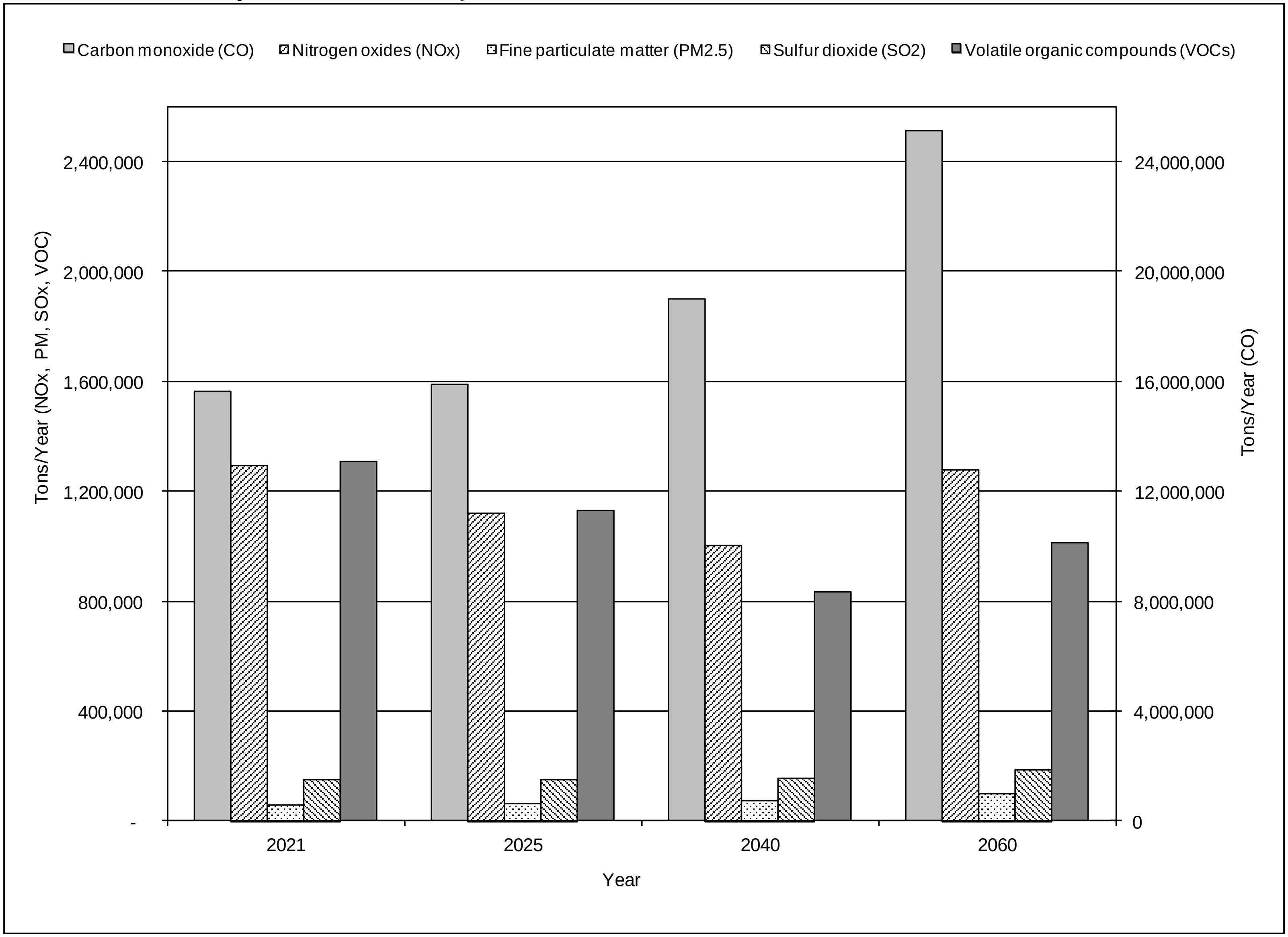


Table 4.2.2-2 lists the net change in nationwide criteria pollutant emissions from passenger cars and light trucks for each of the criteria pollutants and analysis years compared to the No Action Alternative. Figure 4.2.2-3 shows these changes in percentages for 2040. As a general trend, emissions of each pollutant decrease from Alternatives 2 through 4 as each successive alternative becomes more stringent. However, the magnitudes of the declines are not consistent across all pollutants, and there are some increases, reflecting the complex interactions between tailpipe emission rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the proposed standards, upstream emission rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, the proportion of EVs in the passenger car and light truck population, and increases in VMT. Under Alternatives 2 and 3, the greatest relative reductions in emissions among the criteria pollutants occur for SO_2, for which emissions decrease by as much as 38 percent by 2060 compared to the No Action Alternative. Emissions of $PM_{2.5}$ and VOCs under Alternatives 2 and 3 decrease by 19 percent or less compared to the No Action Alternative. Emissions of NO_x under Alternatives 2 and 3 decrease by 4 percent or less, and emissions of CO increase by up to 4 percent compared to the No Action Alternative. Under Alternative 4 the greatest relative reductions in emissions among the criteria pollutants occur for VOCs, for which emissions decrease by as much as 42 percent by 2060. Emissions of $PM_{2.5}$ decrease by as much as 22 percent, SO_2 by as much as 18 percent, CO by as much as 10 percent, and NO_x by as much as 6 percent by 2060.

The differences between one action alternative and another in national emissions of criteria air pollutants range from small (1 percent or less) to large (30 percent) in the same year. The small differences are not expected to lead to measurable changes in ambient concentrations of criteria pollutants. The large differences all result in lower emissions and consequently lower ambient concentrations of criteria pollutants.

Table 4.2.2-3 summarizes the criteria air pollutant analysis results by nonattainment area. Tables in Appendix B list the emissions changes for each nonattainment area. For CO, NO_x, and $PM_{2.5}$, most nonattainment areas would experience increases in emissions across all years under Alternatives 2 and 3 (and Alternative 4 for NO_x), but decreases in CO and $PM_{2.5}$ emissions across all years under Alternative 4. For SO_2 and VOCs, most nonattainment areas would experience decreases in emissions across all alternatives and years.

Table 4.2.2-2. Nationwide Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Cumulative Impacts[a,b]

Pollutant and Year	Alternative 1[c]	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Carbon monoxide (CO)				
2021	0	33,155	39,228	-4,328
2025	0	87,346	69,074	-238,612
2040	0	**429,285**	143,280	-1,813,090
2060	0	**1,046,918**	**565,749**	-2,248,281
Nitrogen oxides (NO_x)				
2021	0	-4,397	-5,692	-5,071
2025	0	-9,575	-10,602	-8,335
2040	0	-25,461	-20,237	-50,900
2060	0	-49,830	-36,252	-80,541
Particulate matter ($PM_{2.5}$)				
2021	0	-574	-827	-1,745
2025	0	-1,348	-2,178	-3,848
2040	0	-4,233	-7,097	-12,285
2060	0	-8,244	-11,672	-19,535
Sulfur dioxide (SO_2)				
2021	0	-4,037	-5,637	-9,208
2025	0	-9,538	-13,381	-10,676
2040	0	-31,796	-37,623	-10,815
2060	0	-65,686	-69,000	-37,644
Volatile organic compounds (VOCs)				
2021	0	-8,664	-12,719	-29,230
2025	0	-20,888	-36,040	-72,765
2040	0	-66,720	-124,903	-242,349
2060	0	-129,170	-196,992	-355,305

a. Emissions changes are rounded to the nearest whole number.
b. Negative emissions changes indicate reductions; positive emissions changes are increases.
c. Emissions changes are shown as zero because the No Action Alternative is the baseline to which emissions under the action alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% decrease compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Figure 4.2.2-3 (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative in 2040 Compared to the No Action Alternative, Cumulative Impacts

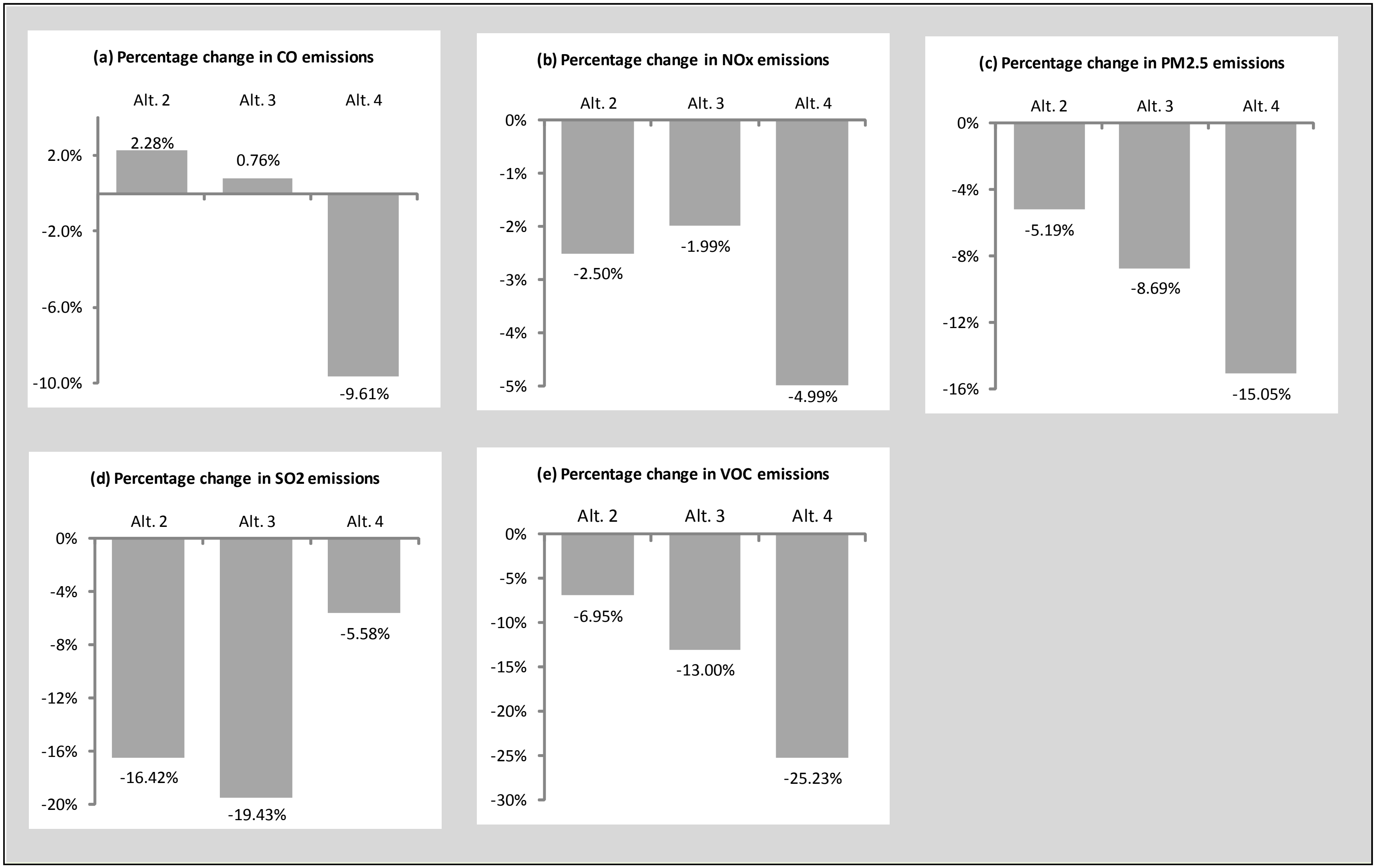


Table 4.2.2-3. Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks, Maximum Changes by Nonattainment Area and Alternative, Cumulative Impacts[a]

Criteria Pollutant	Maximum Increase/ Decrease	Change (tons/ year)	Year	Alternative	Nonattainment Area (Pollutant(s))
Carbon monoxide (CO)	Maximum Increase	50,728	2060	2	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-108,273	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
Nitrogen oxides (NO_x)	Maximum Increase	1,857	2060	3	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)
	Maximum Decrease	-9,531	2060	4	Houston-Galveston-Brazoria, TX (ozone)
Particulate matter ($PM_{2.5}$)	Maximum Increase	63	2060	2	Dallas-Fort Worth, TX (ozone)
	Maximum Decrease	-1,262	2060	4	Houston-Galveston-Brazoria, TX (ozone)
Sulfur dioxide (SO_2)	Maximum Increase	120	2040	4	Beaumont-Port Arthur, TX (ozone)
	Maximum Decrease	-6,685	2060	3	Beaumont-Port Arthur, TX (ozone)
Volatile organic compounds (VOCs)	Maximum Increase	22	2060	2	Riverside County (Coachella Valley), CA (ozone)
	Maximum Decrease	-10,129	2060	4	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)

a. Emissions changes are rounded to the nearest whole number.

4.2.2.1.2 Toxic Air Pollutants Overview

Table 4.2.2-4 summarizes the total national emissions of toxic air pollutants from passenger cars and light trucks by alternative for each of the toxic air pollutants and analysis years. The trends for toxic air pollutant emissions across the alternatives are mixed for the same reasons as for criteria pollutants (*see* Section 4.2.2.1.1). Table 4.2.2-4 shows that emissions of acrolein and formaldehyde generally increase from Alternative 1 to Alternative 4. Acetaldehyde emissions increase from Alternatives 1 to 3, but decline under Alternative 4 after 2040. Emissions of 1,3-butadiene are approximately equivalent for each alternative and year (except for decreases under Alternative 4 in 2040 and 2060). Benzene emissions decrease from Alternative 1 to Alternative 4 (except under Alternative 2 in 2060). The trend for DPM emissions from Alternative 1 to Alternative 4 is mixed, although DPM emissions under all the action alternatives remain below the levels under the No Action Alternative. These trends are accounted for by the extent of technologies assumed to be deployed under the different alternatives to meet the different levels of fuel economy requirements.

Table 4.2.2-4. Nationwide Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Cumulative Impacts

Pollutant and Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Acetaldehyde				
2021	6,941	6,950	6,956	6,999
2025	6,545	6,573	6,604	6,646
2040	6,888	7,054	7,140	6,752
2060	8,934	9,319	9,422	8,846
Acrolein				
2021	326	326	327	335
2025	301	303	309	327
2040	315	327	364	398
2060	409	431	486	534
Benzene				
2021	31,548	31,529	31,510	31,390
2025	25,569	25,523	25,417	24,982
2040	18,422	18,363	17,503	15,051
2060	23,126	23,213	21,951	18,366
1,3-Butadiene				
2021	3,567	3,571	3,571	3,575
2025	3,089	3,098	3,100	3,080
2040	2,755	2,811	2,764	2,490
2060	3,537	3,677	3,597	3,187
Diesel particulate matter (DPM)				
2021	9,632	9,389	9,312	9,251
2025	9,928	9,365	9,232	9,352
2040	11,955	10,138	10,468	11,325
2060	15,541	11,723	12,714	14,331
Formaldehyde				
2021	7,729	7,729	7,743	7,907
2025	7,118	7,132	7,251	7,638
2040	7,332	7,509	8,323	9,024
2060	9,501	9,832	11,042	12,094

Figure 4.2.2-4 shows the changes in toxic air pollutant emissions for each alternative for 2040, the mid-term forecast year.

Figure 4.2.2-5 summarizes the changes over time in total national emissions of toxic air pollutants from passenger cars and light trucks under the Preferred Alternative. Figure 4.2.2-5 shows a consistent trend among the toxic air pollutants. Emissions decline from 2021 to 2025 due to increasingly stringent EPA regulation of emissions from vehicles and from reductions in upstream emissions from fuel production, but reach a minimum typically between 2025 and 2040, and increase from 2040 to 2060 due to continuing growth in VMT.

As with criteria pollutant emissions (*see* Section 4.2.2.1.1), total toxic pollutant emissions are made up of four components, consisting of two sources of emissions (downstream and upstream) for each of the two vehicle classes (passenger cars and light trucks) covered by the proposed rule. To show the relationship among these four components for toxic air pollutants, tables in Appendix A break down the total emissions of toxic air pollutants by component.

Table 4.2.2-5 lists the net change in nationwide emissions from passenger cars and light trucks for each of the toxic air pollutants and analysis years compared to the No Action Alternative. Figure 4.2.2-6 shows these changes in percentages for 2040. Table 4.2.2-5 and Figure 4.2.2-6 show that the magnitude of nationwide emission changes tends to increase from 2021 to 2060, and that emissions under Alternatives 2 and 3 are similar to each other for acetaldehyde, 1,3-butadiene, and DPM (in 2021 and 2025), but less similar for acrolein, benzene, DPM (in 2040 and 2060), and formaldehyde. The magnitude of the emissions changes under Alternative 4 is generally greater than under Alternatives 2 and 3, except for DPM.

Many of the differences between one action alternative and another in national emissions of toxic air pollutants are slight, in the range of 1 percent or less. Consequently, such differences are not expected to lead to measurable changes in ambient concentrations of toxic air pollutants. For such small changes, the impacts of those action alternatives would be essentially equivalent.

Table 4.2.2-6 summarizes the air toxics analysis results by nonattainment area.[20] Tables in Appendix B list the estimated emission changes for each nonattainment area. For acetaldehyde, acrolein, DPM, and formaldehyde, most nonattainment areas experience increases in emissions across all years and alternatives. For benzene and 1,3-butadiene the results are mixed, with the number of nonattainment areas that experience increases becoming less, and the number that experience decreases becoming greater under the more stringent alternatives.

[20] EPA has not established NAAQS for airborne toxics. Therefore, none of these areas is nonattainment because of emissions of airborne toxics.

Figure 4.2.2-4. Nationwide Toxic Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) for 2040 by Alternative, Cumulative Impacts

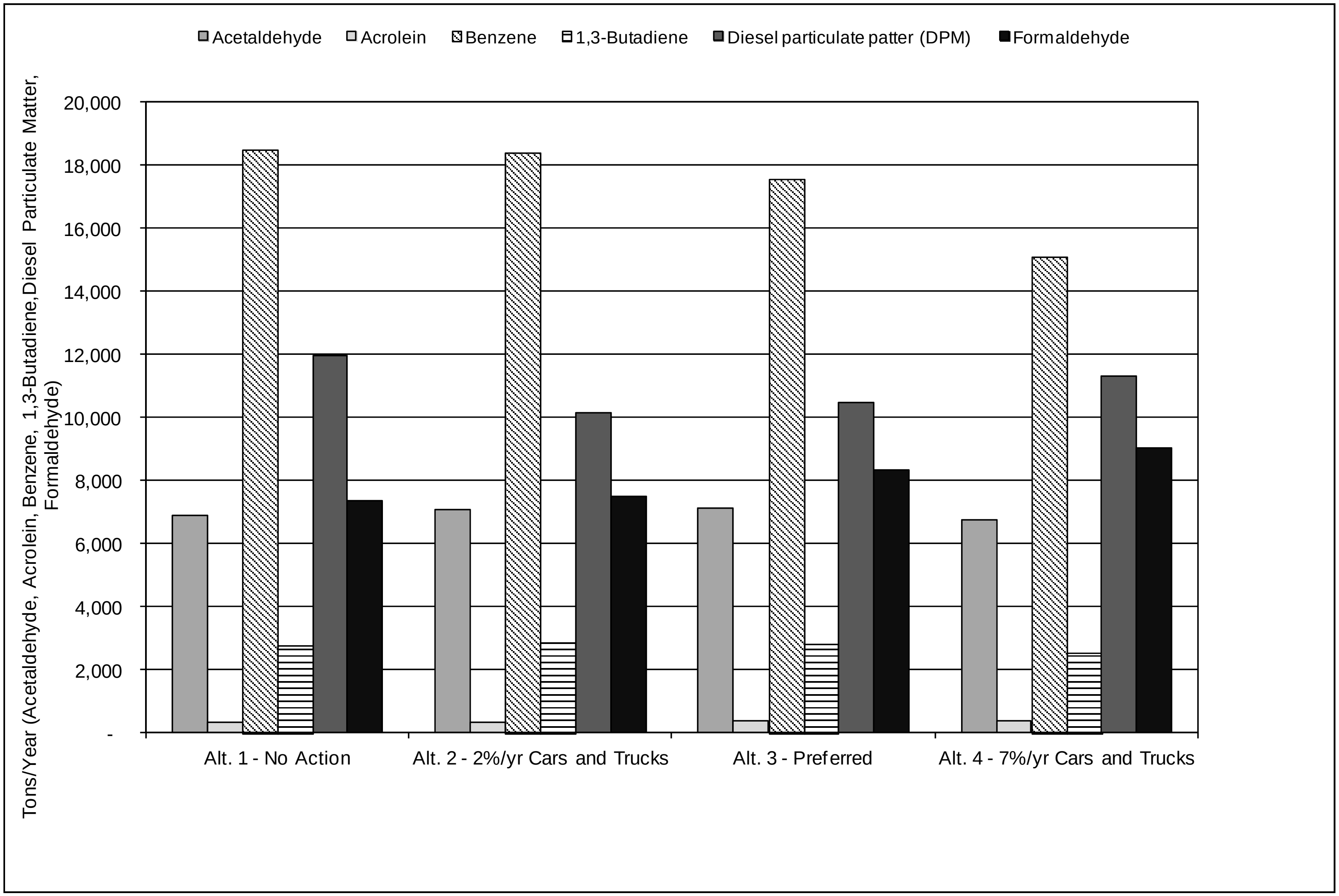


Figure 4.2.2-5. Nationwide Toxic Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) under the Preferred Alternative by Year, Cumulative Impacts

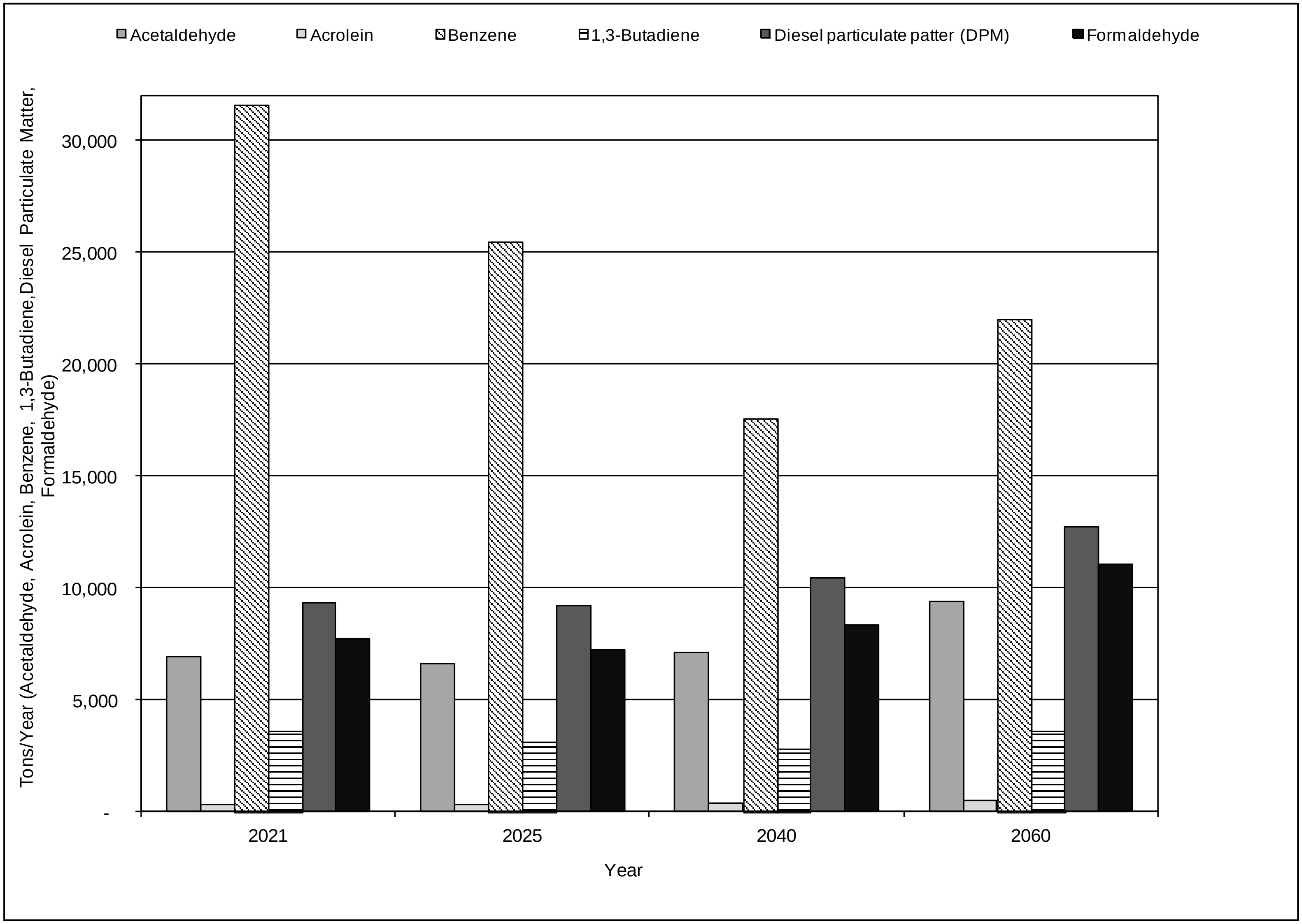


Figure 4.2.2-6 (a)–(f). Nationwide Percentage Changes in Toxic Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative in 2040 Compared to the No Action Alternative, Cumulative Impacts

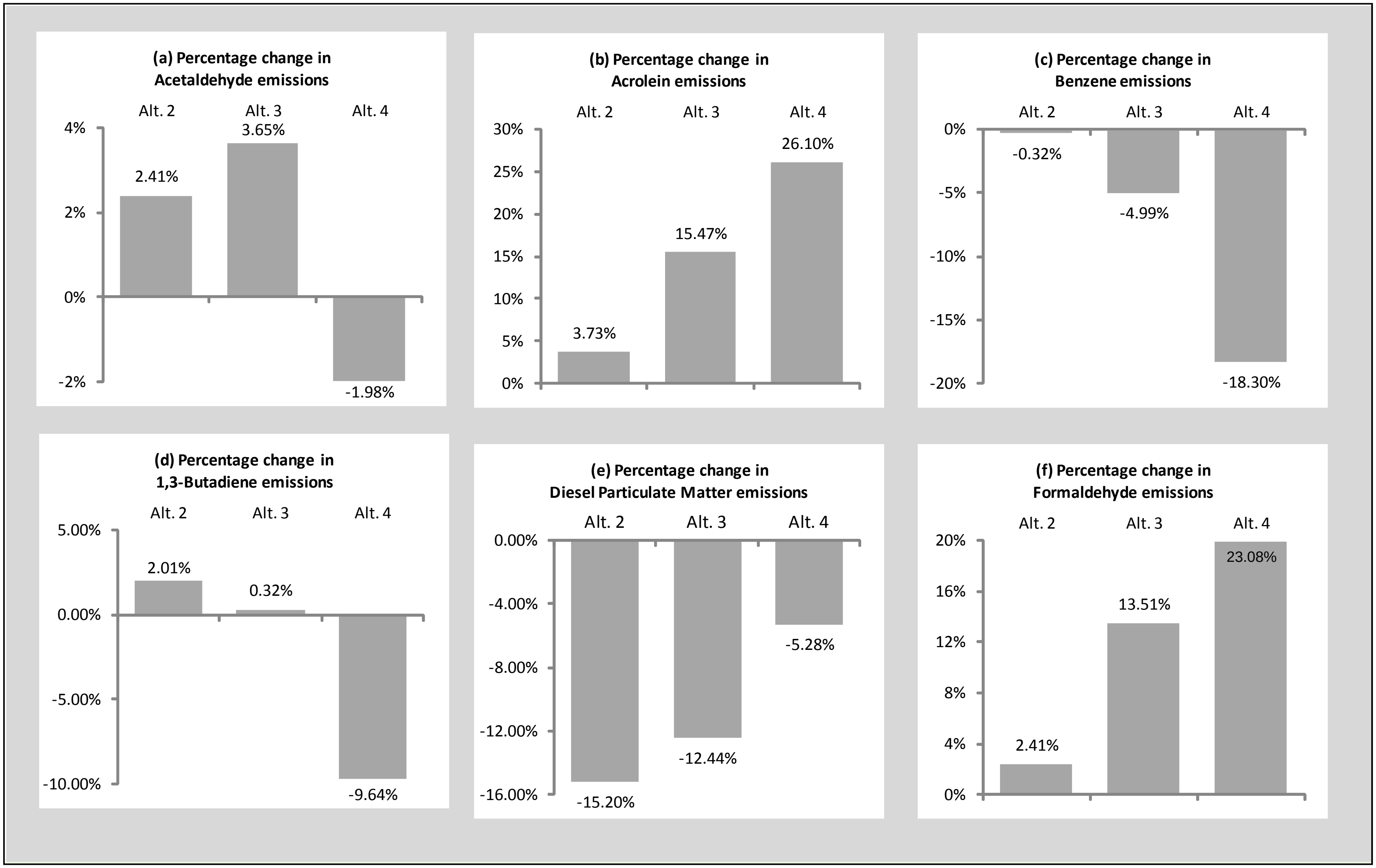


Table 4.2.2-5. Nationwide Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks (tons/year) by Alternative, Cumulative Impacts[a,b]

Pollutant and Year	Alternative 1[c] No Action	Alternative 2 2%/year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/year Cars and Trucks
Acetaldehyde				
2021	0	9	15	57
2025	0	28	59	**102**
2040	0	**166**	**252**	-136
2060	0	**385**	**488**	-88
Acrolein				
2021	0	1	2	**9**
2025	0	2	**8**	**26**
2040	0	**12**	**49**	**82**
2060	0	**21**	**76**	**125**
Benzene				
2021	0	-19	-38	-158
2025	0	-46	-152	-587
2040	0	-59	-919	-3,371
2060	0	87	-1,175	-4,760
1,3-Butadiene				
2021	0	4	4	8
2025	0	10	11	-9
2040	0	**55**	9	-266
2060	0	**141**	**60**	-350
Diesel particulate matter (DPM)				
2021	0	-243	-320	-381
2025	0	-563	-696	-576
2040	0	-1,817	-1,487	-631
2060	0	-3,818	-2,827	-1,210
Formaldehyde				
2021	0	0	14	**178**
2025	0	15	**134**	**520**
2040	0	**177**	**991**	**1,692**
2060	0	**331**	**1,541**	**2,593**

a. Emissions changes are rounded to the nearest whole number.
b. Negative emissions changes indicate reductions; positive emissions changes are increases.
c. Emissions changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which emissions under the action alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% decrease compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Table 4.2.2-6. Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks, Maximum Changes by Nonattainment Area and Alternative, Cumulative Impacts[a]

Hazardous Air Pollutant	Maximum Increase/ Decrease	Change (tons/year)	Year	Alternative	Nonattainment Area
Acetaldehyde	Maximum Increase	24	2060	3	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-20	2060	4	Houston-Galveston-Brazoria, TX (ozone)
Acrolein	Maximum Increase	6	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-2	2060	4	Beaumont-Port Arthur, TX (ozone)
Benzene	Maximum Increase	33	2060	2	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-194	2060	4	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)
1,3-Butadiene	Maximum Increase	7	2060	2	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-16	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
Diesel particulate matter (DPM)	Maximum Increase	189	2060	4	New York-N. New Jersey-Long Island, NY-NJ-CT (ozone, $PM_{2.5}$)
	Maximum Decrease	-544	2060	4	Houston-Galveston-Brazoria, TX (ozone)
Formaldehyde	Maximum Increase	143	2060	4	Los Angeles South Coast Air Basin, CA (CO, NO_x, ozone, PM_{10}, $PM_{2.5}$)
	Maximum Decrease	-125	2060	4	Houston-Galveston-Brazoria, TX (ozone)

a. Emissions changes are rounded to the nearest whole number.

4.2.2.1.3 Health Effects and Monetized Health Benefits Overview

Adverse health effects would decrease nationwide under each of the action alternatives compared to the No Action Alternative (*see* Table 4.2.2-7). Table 4.2.2-8 lists the corresponding monetized health benefits under the action alternatives compared to the No Action Alternative. The reductions in adverse health effects and the monetized health benefits are greater under the more stringent alternatives.

For all health outcomes and years, the health benefits uniformly increase from Alternative 2 (least stringent) to Alternative 4 (most stringent). The benefits also increase steadily from the near future (2021) to later years (2060). These trends are consistent across all health outcomes. Under Alternative 2 in 2021, there is a benefit of up to 1.0 percent. Under Alternative 4 in 2060, this benefit increases to a maximum of 15.4 percent. PM mortality is measured in two ways using the Pope and Laden coefficients. While the number of PM mortalities varies between the two methods, the percent change in mortality across alternatives and years is equal.

The monetized health benefits of these health trends follow similar trends to the changes in health outcomes. The monetized health benefits of each alternative increase (in percentage terms) from Alternative 2 (least stringent) to Alternative 4 (most stringent) and from the near future (2021) to later years (2060). Monetized health benefits are measured in two ways: first, benefits under the Pope methodology versus the Laden methodology (*see* Section 4.1.2.7.2), and second, benefits under a 3 percent discount rate versus a 7 percent discount rate. Because the 7 percent discount rate places less present value on future-year benefits than the 3 percent discount rate, the present-year benefit of reductions in 2060 is approximately 10 percent smaller under the 7 percent discount rate than the 3 percent discount rate. In total, the monetized health benefits range between $220 million and $20 billion, depending on the scenario, alternative, and year. All monetary values are measured in year 2011 dollars.

Sections 4.2.2.2 through 4.2.2.5 describe the results of the analysis of emissions for Alternatives 1 through 4 in greater detail. The magnitude of emissions change from one alternative to the next generally increases between Alternative 2 and Alternative 4 consistent with the required greater overall fuel economy. Health and monetized health benefits increase with each alternative from Alternative 2 through Alternative 4.

Table 4.2.2-7. Nationwide Changes in Health Outcomes from Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks (cases/year) by Alternative, Cumulative Impacts[a]

Outcome and Year	Alternative 1[b]	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
Mortality (ages 30 and older), Pope et al. (2002)				
2021	0	-33	-47	-87
2025	0	-81	-120	-170
2040	0	-310	-450	-610
2060	0	-610	-770	-1,000
Mortality (ages 30 and older), Laden et al. (2006)				
2021	0	-84	-120	-220
2025	0	-210	-320	-440
2040	0	-790	-1,200	-1,600
2060	0	-1,600	-2,000	-2,600
Chronic bronchitis				
2021	0	-22	-32	-59
2025	0	-55	-82	-120
2040	0	-200	-290	-390
2060	0	-390	-490	-670
Emergency room visits for asthma				
2021	0	-32	-45	-82
2025	0	-77	-120	-160
2040	0	-280	-390	-490
2060	0	-550	-680	-850
Work-loss days				
2021	0	-4,200	-6,000	-11,000
2025	0	-10,000	-15,000	-21,000
2040	0	-34,000	-49,000	-67,000
2060	0	-67,000	-84,000	-110,000

a. Negative changes indicate fewer health impacts; positive changes indicate additional health impacts. Values have been rounded.
b. Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

≥ 1% increase	1% or greater increase compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease compared to No Action Alternative
-1% to -10%	1%–10% increase compared to No Action Alternative
> 10% decrease	Greater than 10% decrease compared to No Action Alternative

Table 4.2.2-8. Nationwide Monetized Health Benefits (U.S. million dollars/year, in 2011 dollars) from Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative, Cumulative Impacts[a]

Rate and Year	Alternative 1[b]	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/year Cars and Trucks	Preferred	7%/year Cars and Trucks
3-Percent Discount Rate				
Benefits-per-ton Assuming Premature Mortality Based on Pope et al.(2002)				
2021	0	$240	$350	$640
2025	0	$610	$920	$1,300
2040	0	$2,400	$3,500	$4,800
2060	0	$4,800	$6,000	$8,100
Benefits-per-ton Assuming Premature Mortality Based on Laden et al. (2006)				
2021	0	$590	$850	$1,600
2025	0	$1,500	$2,200	$3,100
2040	0	$5,900	$8,700	$12,000
2060	0	$12,000	$15,000	$20,000
7-Percent Discount Rate				
Benefits-per-ton Assuming Premature Mortality Based on Pope et al. (2002)				
2021	0	$220	$310	$580
2025	0	$540	$820	$1,100
2040	0	$2,200	$3,200	$4,300
2060	0	$4,400	$5,500	$7,400
Benefits-per-ton Assuming Premature Mortality Based on Laden et al. (2006)				
2021	0	$530	$750	$1,400
2025	0	$1,300	$2,000	$2,800
2040	0	$5,400	$7,900	$11,000
2060	0	$11,000	$13,000	$18,000

a. Positive changes indicate greater benefits and fewer health impacts; negative changes indicate fewer benefits and additional health impacts. Values have been rounded.

b. Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the other alternatives are compared.

≥ 1% decrease	1% or greater decrease in benefits compared to No Action Alternative
< 1% (+/-)	Less than 1% increase or decrease in benefits compared to No Action Alternative
-1% to -10%	1%–10% increase in benefits compared to No Action Alternative
> 10% increase	Greater than 10% increase in benefits compared to No Action Alternative

4.2.2.2 Alternative 1: No Action

4.2.2.2.1 Criteria Pollutants

Under the No Action Alternative there is no change after 2016 in the forecast for passenger car and light truck fuel economy in 2016. Current trends in the levels of criteria pollutant emissions from vehicles would continue under the No Action Alternative, with emissions of NO_x and VOCs continuing to decline due to the EPA emission standards (*see* Section 4.1), despite a growth in total VMT from 2021 to 2040, but increasing from 2040 to 2060 due to growth in total VMT during that period (*see* Table 4.2.2-2 and Figure 4.2.2-1). Emissions of CO, $PM_{2.5}$ and SO_2 are predicted to increase from 2021 to 2060 because declines due to the EPA emission standards and fuel economy improvements are more than offset by growth in VMT beginning before 2021. The No Action Alternative would not change these trends and therefore would not result in any change in criteria pollutant emissions nationally or in nonattainment areas beyond changes projected to result from future trends in emissions and VMT (*see* Table 4.2.2-1).

4.2.2.2.2 Toxic Air Pollutants

EPA regulates toxic air pollutants from motor vehicles through vehicle emission standards and fuel quality standards, as discussed in Section 4.1.1.3.1. As with the criteria pollutants, current trends in the levels of toxic air pollutant emissions from vehicles would continue under the No Action Alternative. Emissions would continue to decline in early years due to the EPA emission standards (*see* Section 4.2.1.1), despite a growth in total VMT from 2021 to 2025 or 2040, but would increase from 2025 or 2040 to 2060 due to growth in total VMT during that period (*see* Table 4.2.2-4). The No Action Alternative would not change the current CAFE standards and therefore would not result in any change in toxic air pollutant emissions throughout the United States (*see* Table 4.2.2-6) beyond projected trends shown in Table 4.2.2-4.

Emissions under the No Action Alternative are generally less than those under each of the action alternatives for acetaldehyde, acrolein, and formaldehyde, but greater for benzene and DPM. Results are mixed for 1,3-butadiene. Changes in emissions are greatest in 2060, in which emissions under the action alternatives range up to 23 percent greater and 33 percent smaller than under the No Action Alternative.

4.2.2.2.3 Health Outcomes and Monetized Benefits

Under the No Action Alternative, current trends in the levels of criteria pollutant and toxic air pollutant emissions from vehicles would continue, with emissions of most criteria pollutants continuing to increase from 2021 to 2060 due to a growth in total VMT, which more than offsets reductions due to the EPA vehicle emission standards (*see* Section 4.2.1). The human health-related impacts expected under current trends would continue (*see* Table 4.2.2-7 and 4.2.2-8). The No Action Alternative would not result in any other increase or decrease in human health impacts throughout the United States.

4.2.2.3 Alternative 2: 2 Percent per Year Increase in Fuel Economy

4.2.2.3.1 Criteria Pollutants

Table 4.2.2-2 show the changes in nationwide emissions of criteria pollutants under Alternative 2 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2040. Under Alternative 2, nationwide emissions of $PM_{2.5}$, NO_x, SO_2, and VOCs compared to the No Action Alternative would be reduced. Alternative 2 is the least stringent of all the action alternatives, and the reductions under Alternative 2 generally are smaller than those under the other action alternatives. Emissions of CO under Alternative 2 increase compared to the No Action Alternative in all years because declines due to the EPA emission standards and greater fuel economy are more than offset by growth in VMT due to the rebound effect.

Under Alternative 2, all nonattainment areas would experience reductions in emissions of SO_2 (and most nonattainment areas for emissions of VOCs) compared to the No Action Alternative. Most nonattainment areas would experience slight increases in $PM_{2.5}$ and NO_x emissions, as well as increases in CO emissions. These increases are due to the rebound effect, which more than offsets emission reductions from decreased fuel usage. Tables in Appendix B list the emission changes for each nonattainment area.

4.2.2.3.2 Toxic Air Pollutants

Table 4.2.2-5 shows the changes in nationwide emissions of toxic air pollutants under Alternative 2 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-6 shows these changes in percentages for 2040. Compared to the No Action Alternative, Alternative 2 would result in reduced emissions of benzene (except in 2060), DPM, and formaldehyde (in 2021), increased emissions of acetaldehyde, acrolein and formaldehyde (except in 2021), and approximately equivalent emissions of 1,3-butadiene, for all analysis years. Compared to Alternative 2, emissions under the other action alternatives would be generally higher for acrolein, DPM (in 2040 and 2060), and formaldehyde, and generally lower for benzene and DPM (in 2021 and 2025). Emissions of acetaldehyde and 1,3-butadiene would be higher or lower under the other action alternatives, depending on the analysis year.

At the national level, emissions of all toxic air pollutants could increase because the increases in vehicle emissions due to the rebound effect more than offset reductions in upstream emissions of toxic air pollutants due to improved fuel economy and the resulting decline in the volume of fuel refined and distributed. However, the increases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 2, most nonattainment areas would experience net increases in emissions of most toxic air pollutants in all of the analysis years (*see* Appendix B).

4.2.2.3.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced compared to the No Action Alternative (*see* Table 4.2.2-7). These health benefits increase from 2021 to 2060. As shown in Table 4.2.2-8, the monetized health benefits under Alternative 2 range from approximately $220 million to $12.0 billion. These monetized health benefits are the smallest among all the action alternatives.

4.2.2.4 Alternative 3: Preferred

4.2.2.4.1 Criteria Pollutants

Table 4.2.2-2 show the changes in nationwide emissions of criteria pollutants under Alternative 3 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2040. Figure 4.2.2-2 shows criteria pollutant emissions under Alternative 3 by year. Under this alternative, emissions of all pollutants except CO are reduced compared to the No Action Alternative. CO emissions are increased compared to the No Action Alternative because declines due to the EPA emission standards and greater fuel economy are more than offset by growth in VMT. Alternative 3 generally reduces emissions by a greater amount than Alternative 2, but by less than the more stringent Alternative 4.

Under Alternative 3, all nonattainment areas would experience reductions in emissions of SO_2 and VOCs for all years. Most nonattainment areas would experience slight increases in emissions of NO_x and $PM_{2.5}$ in all years, and a few nonattainment areas would experience large decreases. Most nonattainment areas would experience increases of CO emissions in all years. The increases in emissions of CO and $PM_{2.5}$ occur because declines due to the EPA emission standards and greater fuel economy are more than offset by growth in VMT. The increases in NO_x emissions are due to increases in the diesel vehicle share of total VMT. Tables in Appendix B list the emission changes for each nonattainment area.

4.2.2.4.2 Toxic Air Pollutants

Table 4.2.2-5 shows the changes in nationwide emissions of toxic air pollutants under Alternative 3 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-6 shows these changes in percentages for 2040. Figure 4.2.2-5 shows toxic pollutant emissions under Alternative 3 by year. Compared to the No Action Alternative, Alternative 3 would result in reduced emissions of benzene and DPM, increased emissions of acetaldehyde, acrolein and formaldehyde, and approximately equivalent emissions of 1,3-butadiene for all analysis years. For most pollutants, emissions under Alternative 3 are greater than under Alternative 2, with the exception of benzene, 1,3-butadiene (in 2040 and 2060), and DPM (in 2021 and 2025). Compared to Alternative 4, emissions under Alternative 3 would be lower for acetaldehyde (in 2021 and 2025), acrolein, 1,3-butadiene (in 2021), DPM (in 2025, 2040, and 2060), and formaldehyde; and higher for benzene, acetaldehyde (in 2040 and 2060), DPM (in 2021), and 1,3-butadiene (in 2025, 2040, and 2060).

At the national level, emissions of most toxic air pollutants could increase because the increases in vehicle emissions due to the rebound effect more than offset reductions in upstream emissions of toxic air pollutants due to improved fuel economy and the resulting decline in the volume of fuel refined and distributed. However, as with less stringent alternatives, the reductions in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 3, most nonattainment areas would experience net increases in emissions of all toxic air pollutants in all analysis years (*see* Appendix B), with the exception of benzene emissions, which would decrease in most nonattainment areas in 2025, 2040, and 2060.

4.2.2.4.3 Health Outcomes and Monetized Benefits

Reductions in adverse health effects would occur nationwide under Alternative 3 compared to the No Action Alternative (*see* Table 4.2.2-7). These health benefits increase from 2021 to 2060. As shown in Table 4.2.2-8, the monetized health benefits under Alternative 3 range from approximately $310 million to $15.0 billion. These benefits are greater than those under Alternative 2 for all health outcomes and years, but less than those under Alternative 4.

4.2.2.5 Alternative 4: 7 Percent per Year Increase in Fuel Economy

4.2.2.5.1 Criteria Pollutants

Table 4.2.2-2 show the changes in nationwide emissions of criteria pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2040. Under Alternative 4, nationwide emissions of all criteria pollutants compared to the No Action Alternative would be reduced because of EPA emission standards and greater fuel economy, despite an increase in VMT. These reductions would be greater than under any other alternative, with the exception of NO_x (in 2021 and 2025) and SO_2 (in 2025, 2040, and 2060).

Under Alternative 4, all nonattainment areas would experience reductions in emissions of $PM_{2.5}$, and VOCs for all years, SO_2 (except in 2040), and CO (except in 2021). Most nonattainment areas would experience increases in NO_x emissions in all years and in CO emissions in 2021, while a few nonattainment areas would see larger decreases in these years. SO_2 emissions would decrease in most nonattainment areas in 2040, while a small number of nonattainment areas would experience larger increases in these years. The increases in CO and NO_x emissions in some nonattainment areas occur because declines due to the EPA emission standards and greater fuel economy are more than offset by growth in VMT, while the increases in SO_2 emissions are due to increases in the diesel and EV shares of total VMT. Tables in Appendix B list the emission changes for each nonattainment area.

4.2.2.5.2 Toxic Air Pollutants

Table 4.2.2-5 shows the changes in nationwide emissions of toxic air pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-6 shows these changes in percentages for 2040. Compared to the No Action Alternative, Alternative 4 would result in reduced emissions of acetaldehyde (in 2040 and 2060), benzene, 1,3-butadiene (except in 2021), and DPM, and in increased emissions of acetaldehyde (in 2021 and 2025), acrolein, 1,3-butadiene (in 2021), and formaldehyde. Under Alternative 4, emissions of acetaldehyde (in 2040 and 2060), benzene, 1,3-butadiene (except in 2021), and DPM (in 2021) are less than under all other action alternatives.

At the national level, as for less stringent alternatives, emissions of most toxic air pollutants could increase for the reasons described above (*see* Section 4.2.1.4.2). Under Alternative 4, most nonattainment areas would experience net increases in emissions of acetaldehyde (in 2021 and 2025), acrolein, 1,3-butadiene (in 2021), DPM, and formaldehyde (*see* Appendix B). Benzene emissions would decrease in all nonattainment areas in all years. 1,3-butadiene emissions would decrease in all nonattainment areas in all years except 2021. Acetaldehyde emissions would decrease in all nonattainment areas in 2040 and 2060.

4.2.2.5.3 Health Outcomes and Monetized Benefits

Reductions in adverse health effects nationwide would occur under Alternative 4 compared to the No Action Alternative (*see* Table 4.2.2-7). These health benefits increase from 2021 to 2060. As shown in Table 4.2.2-8, the monetized health benefits under Alternative 4 range from approximately $580 million to $20 billion. The health and monetized health benefits under Alternative 4 are greater than those of all other alternatives.

CHAPTER 5 GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

This section describes how the proposed standards would affect the anticipated pace and extent of future changes in global climate. Although CEQ released draft guidance on consideration of the effects of climate change and greenhouse gas (GHG) emissions under NEPA in February 2010, the draft guidance has not been finalized, and there is currently no formal guidance or regulation for addressing climate change within the structure of an EIS. Pending final guidance, one of the key matters about which NEPA climate change analysts must use their own judgment is how to distinguish between direct and indirect climate change-related impacts of the action alternatives and the cumulative impacts associated with those alternatives.

In this EIS, the discussion of climate change direct and indirect impacts focuses on impacts associated with reductions in GHG emissions due to NHTSA's proposed standards (which are assumed to remain in place at the MY 2025 levels from MY 2026 onward). These standards would affect fuel consumption and emissions attributable to light-duty vehicles through 2100, the end of the analytical period for this section. The discussion of consequences of these standards focuses on GHG emissions and their effects on the climate system (i.e., atmospheric CO_2 concentrations, temperature, sea level, and precipitation).

The cumulative impacts analysis addresses the effects of the proposed standards together with those of past, present, and reasonably foreseeable future actions, including projected increases in fuel economy. These reasonably foreseeable future improvements, beyond those resulting directly or indirectly from the proposed rule, would have additional effects on fuel consumption and emissions attributable to light-duty vehicles through 2100. Climate modeling for the cumulative impacts analysis applies different assumptions about the effect of broader global GHG policies on emissions outside the U.S. light-duty vehicle fleet. The analysis of cumulative impacts also extends the discussion of consequences to include not only the immediate effects of GHG emissions on the climate system (i.e., atmospheric CO_2 concentrations, temperature, sea level, and precipitation), but also the impacts of changes in the climate system on key resources (e.g., freshwater resources, terrestrial ecosystems, and coastal ecosystems).

This chapter is organized as follows:

- Section 5.1 introduces key topics on GHGs and climate change.
- Section 5.2 describes the affected environment in terms of current and anticipated trends in GHG emissions and climate.
- Section 5.3 outlines the methodology NHTSA used to evaluate climate effects.
- Section 5.4 describes the direct, indirect, and cumulative environmental impacts of the Proposed Action and alternative actions that NHTSA considered.
- Section 5.5 qualitatively describes the cumulative impacts of climate change on key natural and human resources.
- Section 5.6 qualitatively describes the cumulative non-climate effects of CO_2.

5.1 Introduction

This EIS draws primarily on panel-reviewed synthesis and assessment reports from the Intergovernmental Panel on Climate Change (IPCC), the U.S. Climate Change Science Program, the National Research Council, the Arctic Council, and the U.S. Global Change Research Program. It also cites EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act* (EPA 2009e), which heavily relied on those major international or national scientific assessment reports. NHTSA similarly relies on assessment reports, because these reports assess numerous individual studies to draw general conclusions about the state of science; are reviewed and formally accepted by, commissioned by, or in some cases authored by U.S. Government agencies and individual government scientists; and in many cases, reflect and convey the consensus conclusions of expert authors. These sources have been vetted by both the climate change research community and by the U.S. Government and are the foundation for the discussion of climate change in this EIS.

This EIS also draws on peer-reviewed panel reports and literature that has been published since the release of the IPCC, the U.S. Climate Change Science Program, and the U.S. Global Change Research Program panel-reviewed reports, to provide the most current review of climate change science. Because the recent peer-reviewed literature has not been assessed or synthesized by an expert panel, these sources supplement, but do not supersede, the findings of the panel-reviewed reports. In virtually every case, the recent literature corroborates the findings of the panel reports.

The level of detail regarding the science of climate change in this EIS, and NHTSA's consideration of other studies that demonstrate the potential impacts of climate change on health, society, and the environment, are provided to help inform the public and decisionmakers, consistent with NHTSA's approach in its EISs for the MY 2012–2016 CAFE standards and the MY 2014–2018 HD vehicle standards.

5.1.1 Uncertainty within the IPCC Framework

The IPCC reports communicate uncertainty and confidence bounds using commonly understood, but carefully defined, words in italics, such as *likely* and *very likely*, to represent likelihood of occurrence. The *IPCC Fourth Assessment Report Summary for Policymakers* (IPCC 2007d) and the *IPCC Fourth Assessment Synthesis Report* (IPCC 2007e) briefly explain this convention.[1] The IPCC Guidance Notes for Lead Authors of the *IPCC Fourth Assessment Report on Addressing Uncertainties* (IPCC 2005) provides a more detailed discussion of the IPCC treatment of uncertainty.

This EIS uses the IPCC uncertainty language (always noted in italics) throughout Chapter 5 when discussing qualitative environmental impacts on specific resources. The reader should refer to the referenced IPCC documents to gain a full understanding of the meaning of those uncertainty terms in the context of the IPCC findings.[2]

As addressed in the *IPCC Fourth Assessment Synthesis Report*, uncertainties can be classified in several ways. "Value uncertainties" and "structural uncertainties" are two primary types of

[1] The IPCC is currently updating its findings and plans to release a Fifth Assessment Report in 2014.
[2] NHTSA notes that these terms could have different meanings than language describing uncertainty used elsewhere in the EIS, in accordance with CEQ regulations requiring an agency to acknowledge areas of scientific uncertainty. *See* Section 2.3.4.

uncertainties. When data are inaccurate or do not fully represent the phenomenon of interest, value uncertainties arise. These types of uncertainties are typically estimated with statistical techniques and then expressed probabilistically. An incomplete understanding of the process that controls particular values or results generates structural uncertainties. These types of uncertainties are described by presenting the authors' collective judgment of their confidence in the correctness of a result. As stated in the Working Group I assessment, a "careful distinction between levels of confidence in scientific understanding and the likelihoods of specific results" are drawn in the uncertainty guidance provided for the Fourth Assessment Report. Confidence terminology (Table 5.1.1-1) is expressed as degree of confidence in being correct. Likelihood terminology is expressed in probability of an outcome. Table 5.1.1-2 identifies the terms that the IPCC uses to define the likelihood of an occurrence or outcome (where the outcome or result can be estimated probabilistically).

Table 5.1.1-1. Standard Terms Used to Define Levels of Confidence

Confidence Terminology	Degree of Confidence in Being Correct
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

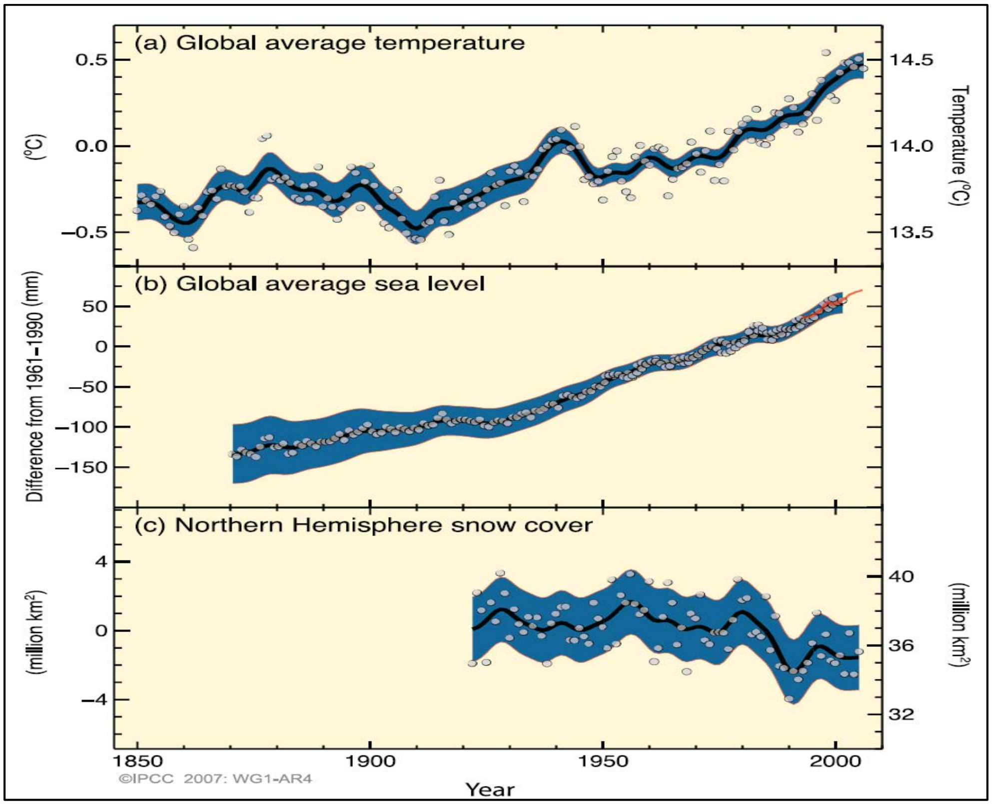
Table 5.1.1-2. Standard Terms Used to Define the Likelihood of An Occurrence of a Climate-related Event

Likelihood Terminology	Likelihood of the Occurrence/Outcome
Virtually certain	Greater than 99% probability
Extremely likely	Greater than 95% probability
Very likely	Greater than 90% probability
Likely	Greater than 66% probability
More likely than not	Greater than 50% probability
About as likely as not	33 to 66% probability
Unlikely	Less than 33% probability
Very unlikely	Less than 10% probability
Extremely unlikely	Less than 5% probability
Exceptionally unlikely	Less than 1% probability

5.1.2 What is Climate Change?

Global climate change refers to long-term (i.e., multi-decadal) trends in global average surface temperature, precipitation, ice cover, sea level, cloud cover, sea-surface temperatures and currents, and other climatic conditions. Over the twentieth century, Earth's global average surface temperature rose by approximately 0.74 °C (1.3 °F) (EPA 2009e, IPCC 2007d, NRC 2010c); global average sea level has been gradually rising, increasing approximately 0.17 meters (6.7 inches) during the twentieth century (IPCC 2007d); in the Atlantic Ocean, the maximum rate of change over the last 50 years has been more than 2 millimeters (0.08 inch) per year observed in a band running east-northeast from the U.S. east coast (EPA 2009e, IPCC 2007a); Arctic sea-ice cover has been decreasing at a rate of approximately 4.1 percent per decade since 1979, with faster decreases of 7.4 percent per decade in summer; and the extent and volume of mountain glaciers and snow cover have been decreasing (EPA 2009e, IPCC 2007d) (*see* Figure 5.1.2-1).

Figure 5.1.2-1. Changes in Temperature, Sea Level, and Northern Hemisphere Snow Cover[a]



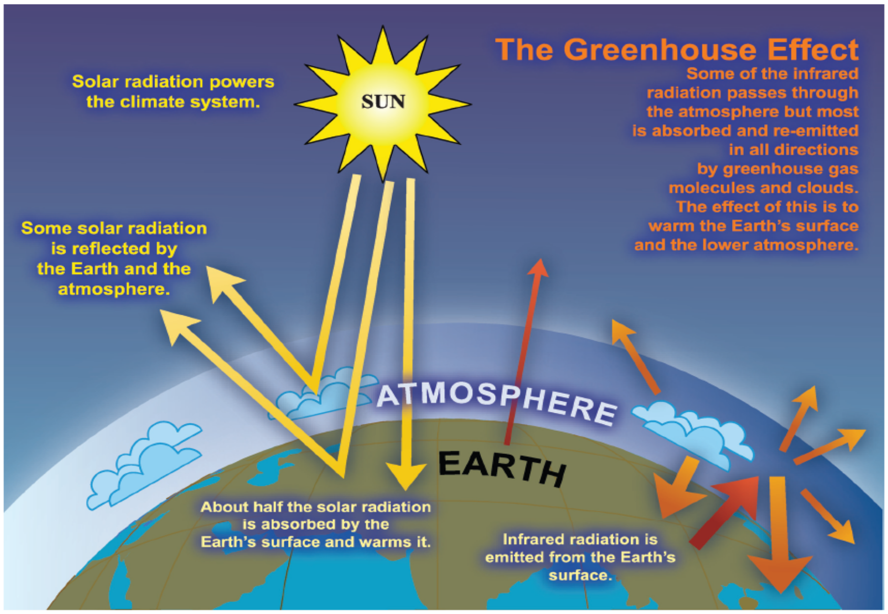
a. Source: IPCC 2007d.

5.1.3 What Causes Climate Change?

Earth absorbs heat energy from the sun and returns most of this heat to space as terrestrial infrared radiation. GHGs trap heat in the lower atmosphere (the atmosphere extending from Earth's surface to approximately 9 to 14 miles above the surface), absorb heat energy emitted by Earth's surface and lower atmosphere, and re-radiate much of it back to Earth's surface, thereby causing warming. This process, known as the "greenhouse effect," is responsible for maintaining surface temperatures warm enough to sustain life (*see* Figure 5.1.3-1). Human activities, particularly fossil-fuel combustion, lead to the presence of increased concentrations of GHGs in the atmosphere; this buildup of GHGs is changing Earth's energy balance.

The observed changes in the global climate described in Section 5.4 are largely a result of GHG emissions from human activities. Both EPA and IPCC have recently concluded that "[m]ost of the observed increase in global average temperatures since the mid-20th Century is *very likely* due to the observed increase in anthropogenic [human-caused] GHG concentrations" (EPA 2009e, IPCC 2007d).

Figure 5.1.3-1. The Greenhouse Effect[a]



a. Source: IPCC 2007a, p. 115.

Most GHGs, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor, and ozone, occur naturally. Human activities such as the combustion of fossil fuel for transportation and electric power, the production of agricultural and industrial commodities, and clear-cutting and burning of forests can contribute to very significant increases in the concentrations of these gases in the atmosphere. In addition, several very potent anthropogenic GHGs – including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) – are almost entirely anthropogenic in origin. These gases are produced mainly for use in industrial processes and emitted to the atmosphere (e.g., as a result of leaks in refrigeration and air-conditioning systems).

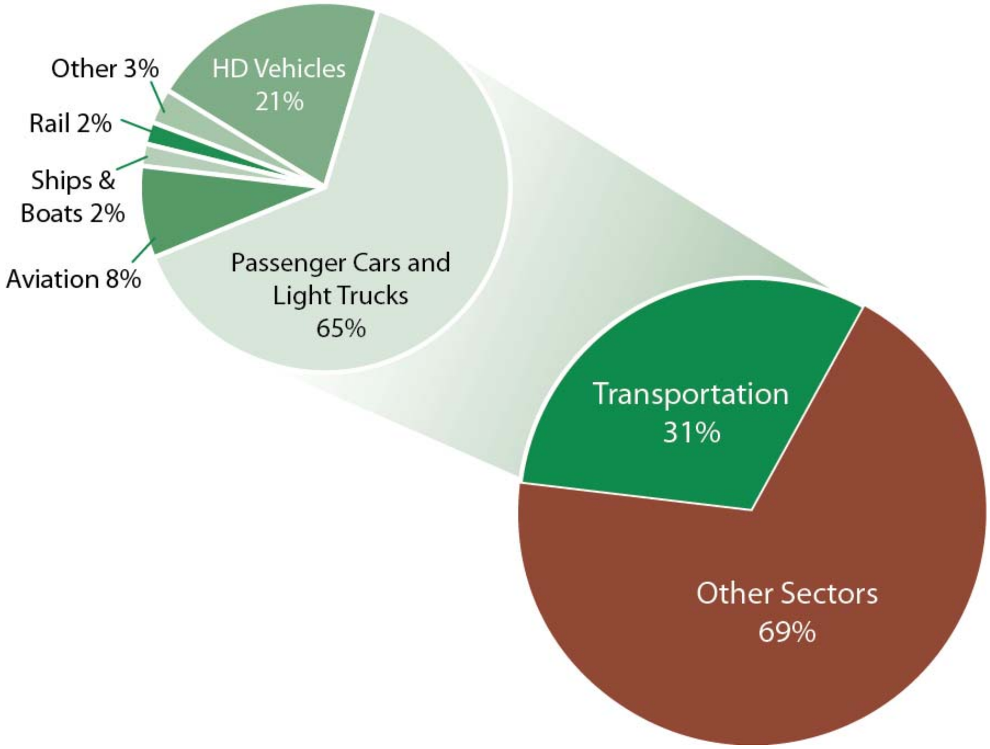
5.1.4 What are the Anthropogenic Sources of Greenhouse Gases?

Human activities that emit GHGs to the atmosphere include the combustion of fossil fuels, industrial processes, solvent use, land-use change and forestry, agricultural production, and waste management. Emissions of CO_2, CH_4, and N_2O from human activities comprise approximately 99 percent of annual anthropogenic GHG emissions addressed by national inventory reports (WRI 2011).[3] Atmospheric concentrations of CO_2, CH_4, and N_2O had, by 2007, increased approximately 38, 149, and 23 percent, respectively, since the beginning of the Industrial Revolution in the mid 1700s (EPA 2009e citing NOAA 2009 and IPCC 2007a, GCRP 2009). Global atmospheric CO_2 concentration has increased from approximately 280 parts per million (ppm) in pre-industrial times to approximately 389 ppm in 2010 (NOAA 2011a). Isotopic and inventory-based studies make clear that this rise in the CO_2 concentration is largely a result of releasing carbon stored underground through the combustion of fossil fuels (coal, petroleum, and natural gas) used to produce electricity, heat buildings, and power motor vehicles and airplanes, among other uses.

[3] Each GHG has a different level of radiative forcing (the ability to trap heat). To compare their relative contributions, gases are converted to carbon dioxide equivalent (CO_2e) using their unique global warming potential (GWP).

Contributions to the buildup of GHGs in the atmosphere vary greatly from country to country and depend heavily on the level of industrial and economic activity, population, standard of living, character of a country's buildings and transportation system, available energy options, and climate. According to World Resources Institute's Climate Analysis Indicators Tool (CAIT), emissions from the United States account for approximately 17.4 percent of total global CO_2 emissions (WRI 2011). EPA's National Greenhouse Gas Inventory for 1990–2009 indicates that, in 2009, the U.S. transportation sector contributed 31.2 percent of total U.S. CO_2 emissions, with passenger cars and light trucks accounting for 64.6 percent of total U.S. CO_2 emissions from transportation (EPA 2011g). Therefore, approximately 20.2 percent of total U.S. CO_2 emissions are from passenger cars and light trucks, and these vehicles in the United States account for 3.5 percent of total global CO_2 emissions (based on comprehensive global CO_2 emissions data available for 2005).[4] Figure 5.1.4-1 shows the proportion of U.S. emissions attributable to the transportation sector and the contribution of each mode of transportation to U.S. emissions.

Figure 5.1.4-1. Contribution of Transportation to U.S. CO_2 Emissions and Proportion Attributable by Mode, 2009[a,b]



a. Source: EPA 2011g.
b. HD = heavy-duty.

[4] Percentages exclude land-use change and forestry and exclude international bunker fuels (i.e., international marine and aviation travel).

5.1.5 Evidence of Climate Change

Observations and studies reporting trends from around the world demonstrate that Earth is undergoing climatic change much more quickly than would be expected from natural variations. As stated in a recent National Research Council (NRC) report, "There is a strong, credible body of evidence, based on multiple lines of research, documenting that climate is changing and these changes are in large part caused by human activities" (NRC 2010c). The global average surface temperature is rising, with decades from 1970 to 2009 being progressively warmer than prior decades, with the warmest temperatures observed during 2000 to 2009 (Arndt et al. 2010). Nine of the 10 warmest years on record have occurred since 2001 (NCDC 2011). Cold-dependent habitats are shifting to higher altitudes and latitudes, and growing seasons are becoming longer (EPA 2009e, GCRP 2009, IPCC 2007d, Montoya and Raffaelli 2010). Sea level is rising, caused by thermal expansion of the ocean and melting of snow and ice. More frequent weather extremes such as droughts, floods, severe storms, and heat waves have been observed (EPA 2009e, IPCC 2007d). Oceans are becoming more acidic as a result of increasing absorption of CO_2, driven by higher atmospheric concentrations of CO_2 (EPA 2009e, NRC 2010a, NRC 2010b, GCRP 2009, National Science and Technology Council 2008). Recent evidence suggests that oceans have become 30 percent more acidic since the Industrial Revolution (Allison et al. 2009 citing McNeil and Matear 2008, Orr et al. 2005, and Riebsell et al. 2009). Statistically significant trends based on various indicators of climate change have been observed on every continent (Rosenzweig et al. 2008). Additional evidence of climate change is discussed throughout this section.

5.1.6 Future Climatic Trends and Expected Impacts

As the world population grows over the twenty-first century, accompanied by industrialization and increases in living standards in developing countries, fossil-fuel use and resulting GHG emissions are expected to grow substantially unless there is a significant shift away from deriving energy from fossil fuels. Based on the current trajectory, the IPCC projects that the atmospheric CO_2 concentration could rise to more than three times pre-industrial levels by 2100 (EPA 2009e, IPCC 2007d). The effects of CO_2 in the atmosphere will persist beyond 2100. If current trends continue, this elevation in atmospheric CO_2 concentrations will persist for many centuries, with the potential of temperature anomalies continuing much longer (Archer et al. 2009a, Archer and Brovkin 2008, Eby et al. 2009, Montenegro et al. 2007).

By 2100, the IPCC projects an average increase in surface temperature of 1.8 °C (3.2 °F) to 4.0 °C (7.2 °F) compared to 1980 through 1999 levels for a number of emissions scenarios, with a likely range of 1.1 °C (2.0 °F) to 6.4 °C (11.5 °F) when including uncertainty regarding climate science. Elevated global average temperatures could persist even if atmospheric CO_2 concentrations decline. Because of the heat capacity of the oceans, centuries are required to realize all the warming from a given level of CO_2 concentrations. Therefore, while reductions in or stabilization of CO_2 concentrations will slow the rate of temperature rise, temperatures will not drop from these reductions until the ocean has reached an equilibrium with the atmosphere (Matthews and Caldeira, 2008). In a multi-millennial simulation of the long-term temperature increase associated with cumulative anthropogenic CO_2 emissions similar to what would be released from burning known fossil fuel reserves, Eby et al. (2009) found that up to two-thirds of the maximum increase in global average temperature could persist for centuries.

In addition, the IPCC projects that this temperature increase will impact sea level, causing a rise of 0.18 meters (0.6 feet) to 0.59 meters (1.9 feet) due only to thermal expansion and the melting of glaciers and small ice caps; even greater rise is projected if ice streams draining the

Greenland and Antarctic ice sheets accelerate. Satellite observations suggest such changes are beginning, and recent studies indicate that sea-level rise could be even greater, and have estimated ranges of 0.8 to 2.0 meters (2.6 to 6.6 feet) (Pfeffer et al. 2008), 0.5 to 1.4 meters (1.6 to 4.6 feet) (Rahmstorf 2007), and 0.97 to 1.56 meters (3.2 to 5.1 feet) (Vermeer and Rahmstorf 2009) by 2100. The National Research Council suggests a more modest increase in sea level of 0.5 to 1.0 meter (1.6 to 3.3 feet) by 2100 (NRC 2010a). Delaying reductions in anthropogenic GHG emissions will increase the concentration at which CO_2 stabilizes in Earth's atmosphere, increasing the risk of catastrophic climate change (Allen et al. 2009, Lowe et al. 2009, Mignone et al. 2008, Vaughan et al. 2009).

In addition to increases in global average temperature and sea level, climate change is expected to have many environmental, human health, and economic consequences. For a more in-depth analysis of the future impacts of climate change on various sectors, *see* Section 5.5 of this EIS.

5.1.7 Black Carbon

In addition to GHGs, other emissions such as black carbon affect Earth's energy balance. Black carbon is an aerosol that forms during incomplete combustion of certain fossil fuels (primarily coal and diesel) and biomass (primarily fuel wood and crop waste.[5] A recent report from the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) suggests that the reduction of black carbon emissions could reduce global mean warming rates over the next few decades, while reductions of CO_2 emissions are required for reducing global mean warming over the long term (UNEP and WMO 2011).

There is no single accepted methodology for summarizing in a simple way the range of effects that black carbon emissions have on the climate or representing these effects and impacts in terms of CO_2e, and significant scientific uncertainties remain regarding black carbon's total climate effect.[6] The interaction of black carbon (and other co-emitted aerosol species) with clouds is especially poorly quantified, and this factor is key to any attempt to estimate the net climate impacts of black carbon. Although black carbon is likely to be an important contributor to climate change, it is not feasible to quantify black carbon climate impacts in an analysis of the proposed standards. Nonetheless, a qualitative description of the climatic effects and general characteristics of black carbon follows.

5.1.7.1 Emissions

Globally, developing countries are the primary emitters of black carbon, because they depend more heavily on biomass-based fuel sources for cooking and heating and on diesel vehicles for transport, and have less stringent air emission control standards and technologies. The United States contributes approximately 7 percent of the world's black carbon emissions with transportation being the single largest sector, followed by wildfires and agriculture/prescribed

[5] Black carbon is often referred to as "soot" or "particulate matter," when in fact it is only one *component* of soot, and one *type* of particulate matter. It is sometimes referred to as "elemental carbon," although it is actually a slightly impure form of elemental carbon. As noted by Andreae and Gelencsér (2006), black carbon is often used interchangeably with other similar terms with slightly different definitions. Furthermore, definitions across literature sources are inconsistent.

[6] The range of uncertainty in the current magnitude of black carbon's climate-forcing effect is evidenced by the wide ranges presented in the IPCC Fourth Assessment Report (2007a) and the more recent study by Ramanathan and Carmichael (2008).

burns (Battye et al. 2002, Bond et al. 2004).[7] Because the U.S. passenger car and light-truck fleet is largely gasoline powered (not diesel), these vehicles are not a significant source of black carbon emissions. There is considerable uncertainty surrounding these emission estimates; Ramanathan and Carmichael (2008) estimate 50 percent uncertainty in global estimates, while the uncertainty in regional emission estimates can range from a factor of 2 to 5.

5.1.7.2 Climatic Interactions

Although black carbon has been an air pollutant of concern for years due to its direct human health effects, climate change experts are currently concerned with it because of its influence on climate change (EPA 2009e, NRC 2010c). Recent studies suggest black carbon is a major contributor to anthropogenic warming as it impacts regional net radiative forcing in several ways: (1) it absorbs incoming or reflected solar radiation, warming the atmosphere around it, (2) it deposits on snow or ice, reducing the albedo[8] and enhancing their melting, (3) as it warms the atmosphere, it triggers cloud evaporation, and (4) as it ages in the atmosphere, it can become hygroscopic, reducing precipitation and increasing the lifetime of clouds (IPCC 2007d, EPA 2009e, Ramanathan and Carmichael 2008, Kopp and Mauzerall 2010, NRC 2010c). The following paragraphs discuss these interactions.

Black carbon absorbs solar radiation and re-emits this energy into the surrounding air, thereby warming it. When black carbon particles are suspended in the air above a dark surface, solar radiation that would have reached the surface is reduced and instead warms the atmosphere, thereby causing a surface cooling effect referred to as surface "dimming" (Ramanathan and Carmichael 2008). When black carbon particles are suspended in the air above a light, reflective surface (such as snow or ice) that would normally reflect sunlight at a high rate, the particles have little effect at Earth's surface. In the atmosphere above Earth's surface, black carbon particles cause warming regardless of the underlying surface characteristics.

When black carbon deposits onto snow and ice, it reduces the albedo as it absorbs incoming solar radiation and contributes to enhanced melting (EPA 2009e, Ramanathan and Carmichael 2008, Flanner et al. 2007). For example, in places where black carbon emissions are high (e.g., upwind of the Himalayan glaciers and the snow-laden Tibetan plateau), earlier snowmelt has been observed and attributed to black carbon deposition (Zemp and Haeberli 2007, Meehl et al. 2008, IPCC 2007d). The Arctic has also experienced accelerated spring melting and the lengthening of the melt season in response to black carbon deposition (Quinn et al. 2008). In fact, recent research indicates that black carbon has contributed approximately 0.5 to 1.4 °C (0.9 to 2.52 °F) to Arctic warming since 1890 (Shindell and Faluvegi 2009).

The complex interaction of black carbon with the radiative properties of clouds is an area under active research. Some aerosols suppress formation of larger cloud droplets, which can extend the life of the cloud and increase cloud cover (Ramanathan and Carmichael 2008). In addition, reducing precipitation can extend the atmospheric lives of aerosols. Although initially

[7] Bond et al. (2004) estimated global black carbon emissions (in $PM_{2.5}$) to be 8,000 gigagrams. Battye et al. (2002) calculated total U.S. black carbon emissions at 433 gigagrams; the EPA 2001 National Emissions Inventory (NEI) database provides fine particle ($PM_{2.5}$) emissions that were then proportioned to black carbon for U.S. on-road diesel vehicles (65 to 89 gigagrams) and on-road gasoline vehicles (16 to 35 gigagrams). U.S. passenger cars and light trucks represent most (97 percent) of on-road gasoline consumed in the United States (EPA 2011g), and therefore are estimated to contribute 4 to 8 percent to the total U.S. black carbon emissions. (Diesel consumption from the fleet is small; therefore, black carbon emissions from diesel consumed by the fleet is likely insignificant.)

[8] Surfaces on Earth (including land, oceans, and clouds, etc.) reflect solar radiation back to space. This reflective characteristic, known as albedo, indicates the proportion of incoming solar radiation the surface reflects. High albedo has a cooling effect, because the surface reflects rather than absorbs most solar radiation.

hydrophobic (i.e., the aerosol does not attract moisture/water vapor), black carbon becomes hygroscopic (i.e., the aerosol attracts moisture/water vapor) as it ages in the atmosphere, thus acting as a cloud condensation nucleus. This increases the number of droplets in clouds, thereby increasing the cloud albedo (Kopp and Mauzerall 2010). Conversely, black carbon radiatively warms the surrounding air as it absorbs solar radiation, which leads to evaporation of cloud droplets by lowering the relative humidity and reducing cloud cover (Ramanathan and Carmichael 2008). An important issue, which can vary by region, is which aerosols – non-black carbon or black carbon – dominate in cloud effects (Ramanathan and Carmichael 2008). The observed weakening of the summertime Indian monsoon has been attributed, in part, to black carbon atmospheric absorption (Ramanathan and Carmichael 2008, Meehl et al. 2008).

5.1.7.3 Net Radiative Effect

A recent study suggests that black carbon has more than half of the positive radiative forcing effect of CO_2 and has a larger forcing effect than other GHGs, including CH_4 and N_2O (Ramanathan and Carmichael 2008). This study estimates that black carbon contributes a net global radiative forcing of more than 0.9 watts per square meter, which is more than twice that estimated by the IPCC (2007a). However, there is great uncertainty associated with these estimates. The different treatment of black carbon across global-scale modeling studies and the variation in regional concentrations hinders obtaining a consistent estimate of its radiative effects. For example, modeling studies vary in how several key factors are weighted, including emission source strength and categories, changes in particle properties as it “ages” in the atmosphere, and the vertical distribution of black carbon (Ramanathan and Carmichael 2008, Jacobson 2010, Kopp and Mauzerall 2010).

5.1.7.4 Comparison to Properties of Greenhouse Gases

Black carbon has a much shorter atmospheric lifespan than GHGs. The U.S. Climate Change Science Program (CCSP 2009a) estimates the life of black carbon in the atmosphere as being approximately 1 to 2 weeks, generally depending on meteorological conditions. This is quite short compared to the atmospheric life of CO_2 in the atmosphere.[9] This short life suggests black carbon’s effects are greatest near the emission source; however, the nearby air molecules heated by black carbon’s absorption of solar radiation can travel long distances, spreading this acquired warmth (Jacobson 2010). Given that the atmospheric loading of black carbon depends on being continually replenished, reductions in black carbon emissions can have an almost immediate (i.e., about a week) effect on radiative forcing.

[9] “About 50% of a CO_2 increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years” (IPCC 2007a).

5.2 Affected Environment

This section describes the affected environment in terms of current and anticipated trends in GHG emissions and climate. Effects of emissions and the corresponding processes that affect climate involve very complex processes with considerable variability, which complicates the measurement and detection of change. Recent advances in the state of science, however, are contributing to an increasing body of evidence that anthropogenic GHG emissions are affecting climate in detectable and quantifiable ways.

This section begins with a discussion of emissions and then turns to climate. Because GHG emissions and climate impacts occur at not only the national scale (i.e., the scale of the alternatives under consideration) but also at the global scale, both discussions include description of conditions globally and in the United States. Many themes in the discussions regarding conditions in the United States reappear in the global discussions.[10]

5.2.1 Greenhouse Gas Emissions (Historic and Current)

5.2.1.1 Global Emissions

Although humans have always contributed some level of GHG emissions to the atmosphere through activities like farming and land clearing, substantial anthropogenic contributions did not begin until the mid 1700s with the onset of the Industrial Revolution. People began burning coal, oil, and natural gas to light their homes, power trains and cars, and run factories and industrial operations. Today, the burning of fossil fuels is still the primary source of energy for the world, and is the predominant source of GHG emissions.

Levels of atmospheric CO_2 have been rising rapidly. For approximately 10,000 years before the Industrial Revolution, atmospheric CO_2 levels were 280 ppm (plus or minus 20 ppm). Since the Industrial Revolution, CO_2 levels have risen to approximately 389 ppm in 2010 (NOAA 2011a). In addition, the concentrations of CH_4 and N_2O in the atmosphere increased 149 and 23 percent, respectively, by 2007 (EPA 2009e, NOAA 2009, Peterson and Barringer 2009).

In 2005, gross global GHG emissions were estimated to be 44,127 $MMTCO_2e$, a 20.3 percent increase since 1990[11] (WRI 2011). In general, global GHG emissions have increased regularly, although annual increases vary according to a variety of factors (e.g., weather, energy prices, and economics).

The primary GHGs emitted are CO_2, CH_4, N_2O, and the fluorinated gases HFCs, PFCs, and SF_6. In 2005, CO_2 emissions comprised 77 percent of global emissions on a GWP-weighted basis, followed by CH_4 (15 percent) and N_2O (7 percent). Collectively, fluorinated gases represented 1 percent of global emissions covered by national inventories (WRI 2011).

GHGs are emitted from a wide variety of sectors, including energy, industrial processes, waste, agriculture, and forestry. The energy sector is the largest contributor of global GHG emissions, accounting for 64 percent of global emissions in 2005. The next highest contributors to

[10] For NEPA purposes, it is appropriate for NHTSA to consider global environmental impacts. *See* CEQ 1997a (stating that “agencies must include analysis of reasonably foreseeable transboundary effects of proposed actions in their [NEPA] analysis of proposed actions in the United States”).
[11] All GHG estimates cited in Section 5.2.1.1 include contributions from land-use change and forestry, as well as bunker fuels.

emissions are agriculture (14 percent) and land-use change and forestry (12 percent) (WRI 2011).

Transportation CO_2 emissions comprise roughly 12 percent of total global GHG emissions (included in the 64 percent cited above for the energy sector [WRI 2011]). Emissions from transportation are primarily due to the combustion of petroleum-based fuels to power vehicles. Global transportation CO_2 emissions have increased by 35 percent from 1990 to 2005 (WRI 2011).

5.2.1.2 U.S. Emissions

GHG emissions for the United States in 2009[12] were estimated at 6,633.2 million metric tons of CO_2e ($MMTCO_2e$) (EPA 2011g). U.S. emissions comprise approximately 16 percent of global GHGs emitted[13] (WRI 2011). Annual U.S. emissions, which have increased 7 percent since 1990, are heavily influenced by “general economic conditions, energy prices, weather, and the availability of non-fossil alternatives” (EPA 2011g).

Similar to the global trend, CO_2 is by far the primary GHG emitted in the United States, representing 83.0 percent of U.S. GHG emissions in 2009 (EPA 2011g). CH_4 accounts for 10.3 percent of total GHGs on a GWP-weighted basis, followed by N_2O (4.5 percent) and the high-GWP gases (2.2 percent) (EPA 2011g).

Most U.S. emissions are from the energy sector, largely due to CO_2 emissions from the combustion of fossil fuels, which alone account for almost 79 percent of total U.S. emissions (EPA 2011g). The CO_2 emissions due to combustion of fossil fuels are from fuels consumed in the electric power (41 percent of fossil-fuel emissions), transportation (33 percent), industry (14 percent), residential (7 percent), and commercial (4 percent) sectors (EPA 2011g). When U.S. CO_2 emissions are apportioned by end use, transportation is still the single leading source of U.S. emissions from fossil fuels, causing approximately one-third of total CO_2 emissions from fossil fuels (EPA 2011g).[14]

Passenger cars and light trucks – which include sport utility vehicles, pickup trucks, and minivans – account for more than half of U.S. transportation CO_2 emissions, and CO_2 emissions from these vehicles have increased by 17 percent since 1990 (EPA 2011g). This increase was driven by two factors: (1) an increase in use of passenger cars and light trucks and (2) relatively little improvement in their average fuel economy. Population growth and expansion, economic growth, and low fuel prices led to more vehicle miles traveled (VMT) over this period, while the rising popularity of sport utility vehicles and other light trucks kept the average combined fuel economy of new passenger cars and light trucks relatively constant (EPA 2011g). Although emissions from these vehicles typically increase each year, emissions from 2008 to 2009 declined due to a decrease in economic activity associated with the recent recession (EPA 2011g).

[12] Most recent year for which an official EPA estimate is available (EPA 2011g).
[13] Based on global and U.S. estimates for 2005, the most recent year for which a global estimate is available. Excluding carbon sinks from forestry and agriculture.
[14] Apportioning by end use allocates emissions associated with electricity generation to the sectors (residential, commercial, industrial, and transportation) where it is used.

5.2.2 Climate Change Effects (Historic and Current)

In its most recent assessment of climate change, the IPCC states that, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (IPCC 2007d). The IPCC concludes that, "At continental, regional and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones" (IPCC 2007d).

This section provides an overview of observed historical and current climate-change effects and impacts at the global, regional, and national scales. Much of the material that follows is drawn from the following studies, including the citations therein: *Summary for Policymakers* (IPCC 2007d), *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act* (EPA 2009e), *Scientific Assessment of the Effects of Global Change on the United States* (National Science and Technology Council 2008), *Global Climate Change Impacts in the United States* (GCRP 2009), and *Climate Change Indicators in the United States* (EPA 2010c). The impacts associated with these observed trends are further discussed in Section 5.5.

5.2.2.1 Increased Temperatures

The IPCC states that scientific evidence shows that the increase in GHGs (primarily, CO_2, CH_4, and N_2O) since 1750 has led to an increase in global radiative forcing of 2.30 watts per square meter (plus or minus 0.23 watts per square meter) (EPA 2009e, IPCC 2007a). The radiative forcing from increased CO_2 concentrations alone increased by 20 percent between 1995 and 2005, which is the largest increase in the past 200 years (IPCC 2007d).

Average temperatures. This increase in radiative forcing results in higher temperatures, which are being observed. The global average surface temperature has been increasing over the past century. In the past 100 years, the global mean surface temperature has risen by 0.74 plus or minus 0.18 °C (1.3 plus or minus 0.32 °F) (IPCC 2007a). Temperatures are rising at an increasing rate. The average rate of increase over the past century was 0.07 plus or minus 0.02 °C (0.13 plus or minus 0.04 °F) per decade. Over the past 50 years, temperatures have been rising at nearly twice that average rate, or 0.13 plus or minus 0.03 °C (0.23 plus or minus 0.05 °F) per decade (IPCC 2007a). Over the past 30 years, the average global temperature has risen even faster, for an average of 0.29 °F per decade (EPA 2009e citing NOAA 2009). The average Arctic temperature has increased at almost twice the global average rate in the past 100 years. Temperature increases are more pronounced over land; air temperatures over land are warming at about twice the rate as over oceans (IPCC 2007a).

The past decade has been the warmest in more than a century of direct observations, with the average temperature for the contiguous United States rising at a rate near 0.58 °F per decade in the past few decades (EPA 2009e citing NOAA 2009). Similar to the global trend, the U.S. average temperature is now 1.25 °F warmer than at the beginning of the twentieth century, with an average warming of 0.13 °F per decade from 1895 through 2008; this rate of warming is increasing (EPA 2009e citing NOAA 2009). Global ocean temperatures have also continued to warm. For example, in summer 2009 ocean-surface temperatures were 0.58 °C (1.04 °F) above the average global temperature recorded for the twentieth century (Hoegh-Guldberg and

Bruno 2010), and the global ocean surface temperature for January 2010 was the second warmest January on record.

Surface temperatures are not rising uniformly around the globe. Antarctic sea-ice extent shows no substantial average trends, despite inter-annual variability and localized changes, consistent with the lack of warming across the region from average atmospheric temperatures (GCRP 2009).

Extreme temperatures. Across regions of the world including the United States, extreme temperatures have changed significantly over the past 50 years. Hot days, hot nights, and heat waves have become more frequent; cold days, cold nights, and frost have become less frequent (EPA 2009e, IPCC 2007a, GCRP 2009, NRC 2010a). Since 1950, the frequency of heat waves experienced in the United States has increased, although in many regions the heat waves recorded in the 1930s remain the most severe on record. Also, fewer unusually cold days occurred in the past few decades, with fewer severe cold waves for the most recent 10-year period in the record (GCRP 2009).

Weather balloons and satellites have recorded increases in temperatures since 1958 and 1979, respectively (Arndt 2010). In addition, higher temperatures are also independently confirmed by other global observations. For example, scientists have documented shifts to higher latitudes and elevations of certain flora and fauna habitat. In high and mid northern latitudes, the growing season increased an average of approximately 2 weeks during the second half of the twentieth century (EPA 2009e citing IPCC 2007b), and plant flowering and animal spring migrations are occurring earlier (EPA 2009e, IPCC 2007b, NRC 2010a, NRC 2010c). Permafrost top layer temperatures have generally increased since the 1980s (approximately 3 °C [5 °F] in the Arctic), while the maximum area covered by seasonal frozen ground has decreased since 1900 by approximately 7 percent in the Northern Hemisphere, with a decrease in spring of up to 15 percent (EPA 2009e citing Lemke et al. 2007, NRC 2010a).

5.2.2.2 Sea-level Rise

Contributions to sea-level rise. Higher temperatures cause sea level to rise due to both thermal expansion of water and an increased volume of ocean water from melting glaciers and ice sheets. From 1961 to 2003, thermal expansion on average contributed approximately 25 percent to observed sea-level rise, while melting ice contributed less than 50 percent. The full magnitude of sea-level rise was not fully explained by observations (EPA 2009e). Between 1993 and 2003, during which observing systems improved, thermal expansion and melting ice were roughly equal in their effect on sea-level rise (EPA 2009e).

Between 1961 and 2003, global ocean temperature warmed by approximately 0.18 °F from the surface to a depth of 700 meters (0.43 mile) (EPA 2009e, IPCC 2007a). This warming contributed an average of 0.4 plus or minus 0.1 millimeter (0.016 plus or minus 0.0039 inch) per year to sea-level rise (EPA 2009e, IPCC 2007a), because seawater expands as it warms. Mountain glaciers, ice caps, and snow cover have declined on average, contributing further to sea-level rise. Losses from the Greenland and Antarctic ice sheets *very likely* contributed to sea-level rise from 1993 to 2003, and satellite observations indicate that they have contributed to sea-level rise in the years since (Shepherd and Wingham 2007). Using satellite radar to observe changes in monthly ice sheet properties and twin satellites to record minute differences in Earth's gravity over the past 18 years, a recent study has estimated that the Greenland and Antarctic ice sheets have been melting at a rate three times faster than that for mountain glaciers and ice caps (Rignot et al. 2011). For the period 1993 to 2007, Cazanave and Llovel

(2010) suggest that approximately 30 percent of the observed rate of sea-level rise is due to thermal expansion, and approximately 55 percent is due to melting of land ice, thus suggesting that thermal expansion contributes less to sea-level rise than some studies previously stated (e.g. EPA 2009e). Dynamical ice loss (i.e., where a supporting ice shelf situated along the boundary between the glacier and ocean collapses, thereby allowing for the downgradient flow of ice streams within the glacier to reach the ocean) explains most of the Antarctic net mass loss and about half of the Greenland net mass loss; the other half occurred because melting has exceeded snowfall accumulation (IPCC 2007d).

Observed global sea-level rise. Global average sea level rose at an average rate of 1.8 plus or minus 0.5 millimeters (0.07 plus or minus 0.019 inch) per year from 1961 to 2003, with the rate increasing to approximately 3.1 plus or minus 0.7 millimeters (0.12 plus or minus 0.027 inch) per year from 1993 to 2003 (EPA 2009e, IPCC 2007a). Recent reports indicate that since the beginning of satellite measurements in the early 1990s, sea level has actually risen at a slightly greater rate of 3.4 millimeters (0.13 inch) per year (Rahmstorf 2010 citing Cazanave and Llovel 2010). Total twentieth century rise is estimated at 170 plus or minus 50 millimeter (6.7 plus or minus 2 inches) (EPA 2009e, IPCC 2007a). However, since the publication of the IPCC Fourth Assessment Report, a recent study improved the historical estimates of upper-ocean (300 meters to 700 meters [0.19 to 0.43 mile]) warming from 1950 to 2003 by correcting for a recently recognized source of instrument bias (Domingues et al. 2008). The study found the improved estimates demonstrate clear agreement with the decadal variability of the climate models that included volcanic forcing.[15] Furthermore, this study estimated the globally averaged sea-level trend from 1961 to 2003 to be a rise of 1.5 plus or minus 0.4 millimeters (0.063 plus or minus 0.01 inch) per year, with a rise of 2.4 millimeters (0.094 inch) per year evident from 1993 to 2003. This estimate is consistent with the estimated trend of 2.3 millimeters (0.091 inch) per year from tidal gauges after accounting for thermal expansion in the upper ocean and deep ocean, variations in the Antarctic and Greenland ice sheets, glaciers and ice caps, and terrestrial storage. Although there is variation of the rate of sea-level rise among these studies, the estimates agree within the stated ranges of uncertainty.

Observed regional sea-level rise. Sea-level rise is not uniform across the globe. The largest increases since 1992 have been in the western Pacific and eastern Indian Oceans; meanwhile, sea level in the eastern Pacific and western Indian Oceans has actually been falling (EPA 2009e, IPCC 2007a).

Nationally, relative sea level is rising 0.8 to 1.2 inches per decade along most of the Atlantic and Gulf coasts, and a few inches per decade along the Louisiana coast (the faster pace being due to relatively rapid land subsidence); sea level is falling (due to land uplift) at the rate of a few inches per decade in parts of Alaska (National Science and Technology Council 2008, EPA 2009e).

Sea-level rise extends the zone of impact of storm surges and waves from tropical and other storms farther inland, causing coastal erosion and other damage. Resulting shoreline erosion is well documented. Since the 1970s, half of the coastal area in Mississippi and Texas has been eroding by an average of 2.6 to 3.1 meters (8.5 to 10.2 feet) per year. In Louisiana, a full 90

[15] Volcanic eruptions can emit large numbers of particles and gases into the stratosphere. These particles, such as sulfates, scatter sunlight away from Earth's surface, causing cooling (i.e., a negative radiative forcing). These particles have been observed to remain in the stratosphere for more than a year.

percent of the shoreline has been eroding at an average rate of more than 12.0 meters (39 feet) per year (EPA 2009e citing Nicholls et al. 2007).[16]

5.2.2.3 Changes in Precipitation Patterns

As the climate warms, evaporation from land and oceans will increase and more moisture can be held in the atmosphere (GCRP 2009). Depending on atmospheric conditions, this translates to some areas experiencing increases in precipitation events, while other areas are left more susceptible to droughts. Average atmospheric water vapor content has increased since at least the 1980s over land and the oceans, and in the upper troposphere, largely consistent with air temperature increases. As a result of changes in climate including increased moisture content in the atmosphere, heavy precipitation events have increased in frequency over most land areas (National Science and Technology Council 2008).

Global, regional, and national precipitation trends. Long-term trends in global precipitation amounts have been observed since 1900. Precipitation has substantially increased in eastern parts of North and South America, northern Europe, and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia. Spatial and temporal variability for precipitation is high, and data are limited for some regions (IPCC 2007a).

Over the contiguous United States, total annual precipitation increased approximately 6 percent from 1901 to 2005 on average. The greatest increases were noted in the northern Midwest and the South, and there were notable decreases in Hawaii and the Southwest (EPA 2010c). Heavy precipitation events also increased, primarily during the last 3 decades of the twentieth century, and mainly over eastern regions (GCRP 2009). A recent analysis found that 8 of the top 10 years with extreme 1-day precipitation events have been observed from 1990 to 2010 (EPA 2010c).

Global, regional, and national trends in droughts. Longer, more intense droughts caused by higher temperatures and decreased precipitation have been observed in some regions since the 1970s, particularly in the tropics and subtropics. Changes in sea surface temperatures, wind patterns, and decreased snowpack and snow cover have also been linked to droughts (EPA 2009e, IPCC 2007a, NRC 2010c). A recent study found that the duration of the snow season from 1967 to 2008 has decreased by 5 to 25 days in Western Europe, Central and East Asia, and the mountainous western United States (Choi et al. 2010).

Most regions in the United States experienced decreases in drought severity and duration over the twentieth century, although there are exceptions to this trend, such as the severe drought in the Southwest from 1999 to 2008 (EPA 2009e citing IPCC 2007a, National Science and Technology Council 2008) and recent severe drought in the Southeast (GCRP 2009). From 2001 through 2009, 30 to 60 percent of land area in the United States experienced drought conditions at any given time (EPA 2010c).

National streamflow trends. Melting snow and ice, increased evaporation, and changes in precipitation patterns all affect surface water. Stream flow decreased approximately 2 percent per decade over the past century in the central Rocky Mountain region (Field et al. 2007 citing Rood et al. 2005), while in the eastern United States it increased 25 percent in the past 60 years (Field et al. 2007 citing Groisman et al. 2004). Annual peak stream flow (dominated by

[16] "The shoreline erosion in Louisiana is also impacted by human alterations and loss of sediment supply" (EPA 2009e).

snowmelt) in western mountains is occurring at least a week earlier than in the middle of the twentieth century. Winter stream flow is increasing in seasonal snow-covered basins, and the fraction of annual precipitation falling as rain (rather than snow) has increased in the past half century (National Science and Technology Council 2008). Barnett et al. (2008) found that human-caused climate change was responsible for up to 60 percent of the observed changes in river flows, winter air temperature, and snowpack in the western United States. Analytical and modeling results for eight river basins indicate that northwestern and north-central regions of the western United States are becoming wetter, while the southwestern and south-central regions are becoming drier (Bureau of Reclamation 2011).

National trends in snow cover. An empirical analysis of available data indicated that temperature and precipitation impact mountain snowpack in concert with the nature of the impact strongly dependent on factors such as latitude and elevation (Stewart 2009). At high elevations that remain below freezing in winter, precipitation increases have resulted in increased snowpack, while warmer temperatures at mid-elevations have decreased snowpack and led to earlier snowmelt, even with precipitation increases (Kundzewicz et al. 2007). During the second half of the twentieth century, the depth of snow cover in early spring decreased for most of the western United States and Canada, with some areas experiencing up to a 75 percent decrease (EPA 2010c). For North America as a whole, EPA (2010c) found that snow coverage has declined from approximately 3.4 million square miles to 3.2 million square miles from the 1970s to this past decade.

In addition to trends detected in total snow coverage across the entire winter and early spring season, some investigators have found trends for specific months. Total snow-cover area in the United States increased in the November-to-January season from 1915 to 2004 (National Science and Technology Council 2008).[17] In mountainous regions of the western United States, April snow water equivalent has declined 15 to 30 percent since 1950, particularly at lower elevations and primarily due to warming (National Science and Technology Council 2008 citing Field et al. 2007).

5.2.2.4 Increased Incidence of Severe Weather Events

Long-term trends in tropical cyclone activity have been reported, but no clear trend in the number of tropical cyclones each year has been demonstrated. There is observational evidence of an increase in intense tropical cyclone activity correlated with increases of tropical sea-surface temperatures in the North Atlantic since about 1970 (EPA 2009e). Six of the 10 most active hurricane seasons have occurred since the mid 1990s, mirroring the variations in sea surface temperatures of the tropical Atlantic (EPA 2010c). There is also evidence of an increase in extreme wave height characteristics over the past 2 decades, associated with more frequent and more intense hurricanes (CCSP 2008a). However, concerns about data quality and multi-decadal variability persist (EPA 2009e). The World Meteorological Organization (WMO) Sixth International Workshop on Tropical Cyclones in 2006 agreed that "no firm conclusion can be made" on anthropogenic influence on tropical cyclone activity because "there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record" (WMO 2006). Recently, there is a growing confidence in the model projections that climate change may increase hurricane strength, but it is still unclear how the overall frequency of occurrence might change (NRC 2010c).

[17] Snowfall tends to increase as temperature approaches the freezing point because the air can hold more moisture, but above the freezing point, there is a shorter time of freezing conditions reducing the snowfall pack amount.

Evidence is also insufficient to determine whether there are trends in large-scale phenomena such as the Meridional Overturning Circulation (a mechanism for heat transport in the North Atlantic Ocean, by which warm waters are carried north and cold waters are carried toward the equator), or in small-scale phenomena such as tornadoes, hail, lightning, and dust storms (IPCC 2007d).

5.2.2.5 Changes in Ice Cover and Permafrost

Changes in air and ocean temperatures, precipitation onto the ice mass, and water salinity are affecting glaciers, sea-ice cover, and ice sheets. Numerous studies have confirmed that glaciers and ice sheets have significantly shrunk in the past half century. Satellite images have documented the loss of mass from the Greenland ice sheet and the West Antarctic ice sheet (NASA 2009); since 1979, the annual average Arctic sea-ice area has been declining at a rate of 4.1 percent per decade (EPA 2009e citing NSIDC 2009). Warming in the Arctic has proceeded at about twice the rate as elsewhere, leading to decreases in summer sea-ice extent, glacier and ice sheet mass loss, coastal erosion, and permafrost thawing (AMAP 2011).[18] Some Arctic ice that previously was thick enough to last through summer has now thinned enough to melt completely in summer. In 2007, sea-ice extent was approximately 23 percent less than the previous all-time minimum observed in 2005 (EPA 2009e, National Science and Technology Council 2008). Average sea-ice thickness in the central Arctic *very likely* decreased by approximately 3 feet from 1987 to 1997 (EPA 2009e, National Science and Technology Council 2008). In 2003, 62 percent of the Arctic's total ice volume was stored in multi-year ice; in 2008, only 32 percent was stored in multi-year ice (NASA 2009). These area and thickness reductions allow winds to generate stronger waves, which have increased shoreline erosion along the Alaskan coast. Alaska has also experienced increased thawing of the permafrost base of up to 1.6 inches per year since 1992 (EPA 2009e, National Science and Technology Council 2008).

5.2.2.6 Acidification of Oceans

Increasing CO_2 concentrations have forced additional uptake by the oceans, which lowers the pH of the water. When CO_2 dissolves in seawater, the hydrogen ion concentration of the water increases; this is measured as a decline in pH. Compared to the pre-industrial period, the pH of the world's oceans has dropped 0.1 unit (IPCC 2007a). Because pH is measured on a logarithmic scale, this represents a 30 percent increase in the hydrogen ion concentration of seawater, a significant acidification of the oceans. As discussed more fully in Section 5.6, although research on the ultimate impacts of ocean acidification is limited, available observational, laboratory, and theoretical studies indicate that acidification is likely to interfere with the calcification of coral reefs and therefore inhibit the growth and survival of coral reef ecosystems (EPA 2009e, NRC 2010a, NRC 2010c, GCRP 2009, IPCC 2007e).

[18] Permafrost thawing releases CO_2 and CH_4 into the atmosphere (*see* Section 5.5.2).

5.3 Analysis Methodology

The methodology NHTSA used to characterize the effects of the alternatives on climate has three key elements, as follows:

- Analyzing the effects of the Proposed Action and alternatives on GHG emissions
- Estimating the monetized damages associated with CO_2 emissions and reductions attributable to each regulatory alternative
- Analyzing how GHG emissions and reductions under each action alternative affect the climate system (climate effects)

For effects on GHG emissions and the climate system, this EIS expresses results for each alternative in terms of the environmental attribute being characterized (emissions, CO_2 concentrations, temperature, precipitation, and sea level). Comparisons between the No Action Alternative and each action alternative are also presented to illustrate the differences in environmental effects among the alternatives. The impact of each action alternative on these results is measured by the difference in the climate parameter (CO_2 concentration, temperature, sea level, and precipitation) under the No Action Alternative and the climate parameter under that action alternative. For example, the reduction in CO_2 emissions attributable to an action alternative is measured by the difference in emissions under that alternative and emissions under the No Action Alternative.

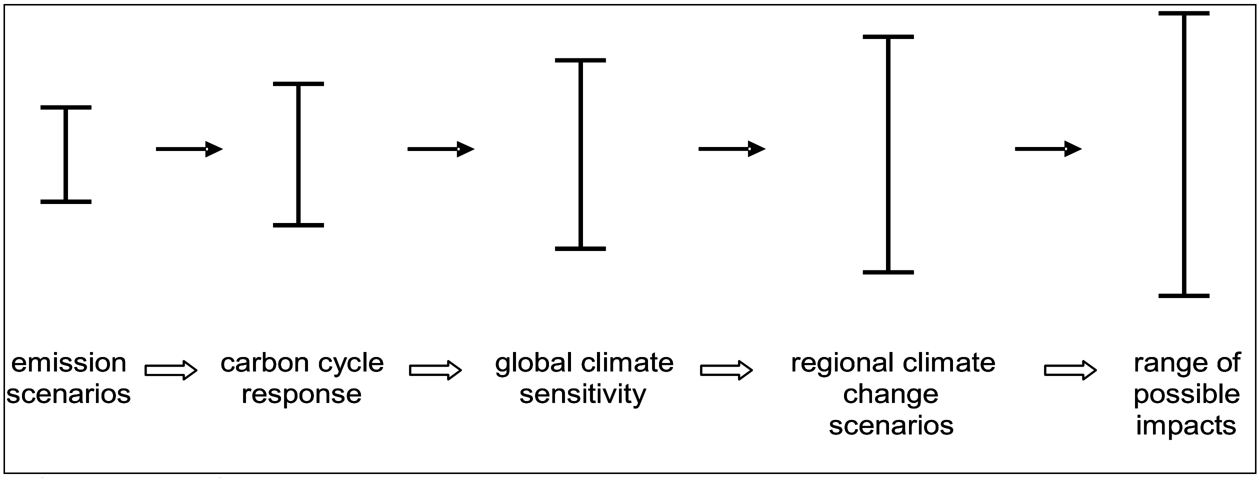
The methods used to characterize emissions and climate effects involve considerable uncertainty. Sources of uncertainty include the pace and effects of technology change in the transportation sector and other sectors that emit GHGs, changes in the future fuel supply and fuel characteristics that could affect emissions, sensitivity of climate to increased GHG concentrations, rate of change in the climate system in response to changing GHG concentrations, potential existence of thresholds in the climate system (which cannot be predicted or simulated), regional differences in the magnitude and rate of climate change, and many other factors.

Moss and Schneider (2000) characterize the "cascade of uncertainty" in climate change simulations (Figure 5.3-1). As indicated in the figure, the emission estimates used in this EIS have narrower bands of uncertainty than the global climate effects, which are less uncertain than regional climate change effects. The effects on climate are, in turn, less uncertain than the impacts of climate change on affected resources (such as terrestrial and coastal ecosystems, human health, and other resources discussed in Section 5.5). Although the uncertainty bands broaden with each successive step in the analytic chain, all values within the bands are not equally likely; the mid-range values have the highest likelihood.

Scientific understanding of the climate system is incomplete; like any analysis of complex, long-term changes to support decisionmaking, evaluating reasonably foreseeable significant adverse impacts on the human environment involves many assumptions and uncertainties. This EIS uses methods and data that represent the best and most up-to-date information available on this topic, and that have been subjected to extensive peer review and scrutiny. The information cited throughout this section that is extracted from the most recent EPA, IPCC, and U.S. Global Change Research Program reports on climate change has endured a more thorough and systematic review process than information on virtually any other topic in environmental science and policy. The tools used to perform the climate change impacts analysis in this EIS, including

MAGICC and the Global Change Assessment Model (GCAM, formerly MiniCAM) reference emission scenario, are widely available and generally accepted in the scientific community.[19]

Figure 5.3-1. Cascade of Uncertainty in Climate Change Simulations[a]



a. Source: Moss and Schneider 2000.

The U.S. Climate Change Science Program Synthesis and Assessment Product 3.1 (SAP 3.1) on the strengths and limitations of climate models (CCSP 2008b) provides a thorough discussion of the methodological limitations regarding modeling. Readers interested in a detailed treatment of this topic will find the SAP 3.1 report useful in understanding the issues that underpin the modeling of environmental impacts of the Proposed Action and the range of alternatives on climate change.

5.3.1 Methodology for Modeling Greenhouse Gas Emissions

The emission estimates include GHG emissions resulting from light-duty vehicle fuel combustion (tailpipe emissions) as well as upstream emissions from the production and distribution of fuel.[20] GHG emissions were estimated by the DOT Volpe National Transportation Systems Center using two models: the CAFE Compliance and Effects (referred to as Volpe) model, described in Section 2.3.1, to calculate tailpipe emissions, and the Greenhouse Gases and Regulated Emissions in Transportation (GREET) model, developed by the U.S. Department of Energy (DOE) Argonne National Laboratory, to estimate emissions associated with production of gasoline and diesel from crude oil as well as emissions associated with the generation of electricity. The Volpe model uses emission factors derived from EPA's Motor Vehicle Emissions Simulator (MOVES).

Emissions under each action alternative were compared against those under the No Action Alternative to determine the impact of the action alternative on emissions. GHG emissions from MY 2017–2060 vehicles were estimated using the methodology described in Section 2.2.3. For the climate analysis, GHG emission trajectories are projected through year 2100. NHTSA estimated GHG emissions for the light-duty vehicle fleet for 2061–2100 by applying the projected rate of change in U.S. transportation fuel consumption over this period from GCAM.[21]

[19] GCAM is used as the basis for the Representative Concentration Pathway (RCP) 4.5 scenario (Thomson et al. 2011).
[20] Section 2.4.1.2 provides more information on the upstream emission factors applied to account for upstream fuel and electricity generation.
[21] The last year for this analysis in which the Volpe model provides estimates of fleet CO_2 emissions is 2060.

For 2061 through 2100, the GCAMReference and GCAM6.0 scenarios project that U.S. road transportation fuel consumption will decline slightly due primarily to (1) assumed improvements in efficiency of internal combustion engine-powered vehicles and (2) increased deployment of non-internal combustion engine vehicles with higher drivetrain efficiencies. However, the projection of road transport fuel consumption beyond 2060 does not change significantly and, therefore, emissions remain relatively constant from 2060 through 2100. The assumptions and methods used to develop the GHG emission estimates for this EIS are broadly consistent with those used in the the MY 2012–2016 CAFE Final EIS (NHTSA 2010b) and the MY 2014–2018 HD Final EIS (NHTSA 2011b).

The emission estimates include global CO_2, CH_4, and N_2O emissions resulting from direct fuel combustion and from the production and distribution of fuel and electricity (upstream emissions). The Volpe model also accounted for and estimated the following non-GHGs: SO_2, NO_x, CO, and VOCs.

Fuel savings from more stringent CAFE standards would result in lower emissions of CO_2, the main GHG emitted as a result of refining, distribution, and use of transportation fuels.[22] There is a direct relationship among fuel efficiency, fuel consumption, and CO_2 emissions. Fuel efficiency describes how much fuel a vehicle requires to perform a certain amount of work (for example, how many miles it can travel or how many tons it can carry per mile traveled). A vehicle is more fuel-efficient if it can perform more work while consuming less fuel. Lower fuel consumption reduces CO_2 emissions directly, because the primary source of vehicle-related CO_2 emissions is the combustion of carbon-based fuel in internal-combustion engines; combustion of a hydrocarbon essentially produces energy (used to power the vehicle), CO_2, and water. Therefore, fuel consumption is directly related to CO_2 emissions, and CO_2 emissions are directly related to fuel efficiency.

For the analysis in this EIS, NHTSA estimated reductions in CO_2 emissions resulting from fuel savings by assuming that the carbon content of gasoline, diesel, and other fuels is converted entirely to CO_2 during the combustion process.[23] Specifically, NHTSA estimated CO_2 emissions from fuel combustion as the product of the volume of each type of fuel consumed (in gallons), its mass density (in grams per gallon), the fraction of its total mass represented by carbon (measured as a proportion), and CO_2 emissions per gram of fuel carbon (the ratio of the molecular weights of CO_2 and elemental carbon).

Reduced fuel consumption also lowers CO_2 emissions that result from the use of carbon-based energy sources during fuel production and distribution. Volpe estimated the global reductions in CO_2 emissions during each phase of fuel and electricity production and distribution (i.e., upstream emissions) using CO_2 emissions rates obtained from the GREET version 1.8d.1 model using the previous assumptions about how fuel savings are reflected in reductions in

[22] For this rulemaking, NHTSA estimated emissions of vehicular CO_2, CH_4, and N_2O emissions, but did not estimate vehicular emissions of HFCs, which are not regulated under NHTSA's action. HFCs are released to the atmosphere only through air-conditioning system leakage, and are not directly related to fuel efficiency. NHTSA's authority under EISA extends only to the regulation of vehicle fuel efficiency. For the reader's reference, CH_4 and N_2O account for 1.8 percent of the tailpipe GHG emissions from passenger vehicles and light trucks, and CO_2 emissions account for the remaining 98.2 percent. Of the total (including non-tailpipe) GHG emissions from passenger vehicles, tailpipe CO_2 represents approximately 94.4 percent, tailpipe CH_4 and N_2O represent approximately 1.8 percent, and HFCs represent approximately 3.9 percent. (Values are calculated from EPA 2011g.)

[23] This assumption results in a slight overestimate of CO_2 emissions, because a small fraction of the carbon content of gasoline is emitted as CO and unburned hydrocarbons. However, the magnitude of this overestimation is likely to be extremely small. This approach is consistent with the recommendation of the IPCC for "Tier 1" national GHG emissions inventories (IPCC 2006).

activity during each phase of fuel production and distribution.[24] The total reduction in CO_2 emissions from improving fuel efficiency under each alternative is the sum of the reductions in motor vehicle emissions from reduced fuel combustion plus the reduction in upstream emissions from a lower volume of fuel production and distribution.

5.3.2 Social Cost of Carbon

This section describes the methodology used to estimate the monetized damages associated with CO_2 emissions and the reductions in those damages that would be attributable to each action alternative. NHTSA adopted an approach that relies on estimates of the social cost of carbon (SCC) developed by the Interagency Working Group on Social Cost of Carbon; this approach is consistent with the analysis in EPA's Draft Regulatory Impact Analysis (RIA) for the MY 2017–2025 rulemaking.

The SCC is an estimate of the monetized climate-related damages associated with an incremental increase in annual carbon emissions. NHTSA multiplied the estimated value of the SCC during each future year by the emission reductions estimated to result during that year from each of the alternatives considered in this EIS to estimate the monetized climate-related benefits associated with CO_2 reductions under each alternative. The following description mirrors the discussion in EPA's Draft RIA and provides details of this analysis.

The SCC is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. The SCC estimates used in this analysis were developed through an interagency process that included DOT/NHTSA, EPA, and other Executive Branch entities, and concluded in February 2010. These SCC estimates were used previously in the benefits analysis for the NHTSA/EPA joint rulemakings to establish MY 2012–2016 CAFE standards and MY 2014–2018 HD vehicle standards.[25] The SCC Technical Support Document (TSD) provides a complete discussion of the methods used to develop these SCC estimates.[26]

The interagency group selected four SCC values for use in regulatory analyses for 2010, which NHTSA has updated for 2011 in this analysis: approximately $5, $23, $37, and $69 per metric ton of CO_2 emissions occurring in 2011, reported in 2009 dollars.[27] The first three values are based on the average SCC from three integrated assessment models, at discount rates of 5, 3, and 2.5 percent, respectively. SCCs at several discount rates are included because the literature shows that the SCC is quite sensitive to assumptions about the discount rate and because there is no consensus on the appropriate rate to use in an intergenerational context. The fourth value is the 95th percentile of the SCC from all three models at a 3 percent discount rate. This value is included to represent higher-than-expected impacts from temperature

[24] Some modifications were made to the estimation of upstream emissions, consistent with EPA assumptions in the joint light-duty vehicle CAFE and GHG emissions rulemaking for MYs 2017–2025. Chapter 4 of EPA's Draft RIA provides more information regarding these modifications.

[25] For a discussion about the application of the SCC, *see* the NPRM.

[26] EPA 2010d. *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group on Social Cost of Carbon*, with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury (February 2010).

[27] The SCC estimates were converted from 2007 dollars to 2009 dollars using a Gross Domestic Product (GDP) price deflator (~1.033) obtained from the Bureau of Economic Analysis, National Income, and Product Accounts (NIPA) Table 1.1.9, Implicit Price Deflators for Gross Domestic Product (using the annual, rather than quarterly, GDP for the United States) (BEA 2011).

change farther out in the tails of the SCC probability distribution. Low-probability, high-impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models, and the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high-temperature outcomes, which in turn lead to higher projections of damages.

The SCC increases over time, because incremental increases in emissions are expected to produce progressively larger incremental damages over future years, as physical and economic systems become more stressed in response to greater climatic change. Note that the interagency group estimated the growth rate of the SCC directly using the three integrated assessment models rather than assuming a constant annual growth rate. This helps ensure that the estimates are internally consistent with other modeling assumptions. Table 5.3.2-1 lists the SCC estimates used in this analysis. Note that the interagency group only provided estimates of the SCC through 2050. Therefore, unlike other elements of the climate change analysis in the EIS, which generally extend to 2100, the SCC covers a shorter time frame.

Table 5.3.2-1 lists global SCC estimates, in constant 2009 dollars per metric ton of CO_2 emitted. These are the average SCCs across all three of the integrated assessment models used in the interagency group SCC analysis. The final column indicates the 95th percentile of the SCC at a 3 percent discount rate averaged across the three models. Annual versions of these values are used in the subsequent calculations in this section.

Table 5.3.2-1. Social Cost of CO_2, 2011–2050 (in 2009 dollars per metric ton)

Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2011	$5.06	$22.62	$36.88	$68.69
2015	$5.89	$24.58	$39.67	$75.20
2020	$7.02	$27.17	$43.07	$83.36
2025	$8.47	$30.58	$47.41	$93.38
2030	$10.02	$33.88	$51.65	$103.30
2035	$11.57	$37.19	$55.99	$113.32
2040	$13.12	$40.49	$60.33	$123.23
2045	$14.67	$43.49	$63.01	$132.01
2050	$16.22	$46.38	$67.14	$140.69

Many serious challenges arise when attempting to assess the incremental economic impacts of CO_2 emissions. A recent report from the National Academies (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of GHGs, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harm associated with climate change will raise serious questions of science, economics, and ethics, and should be viewed as provisional.

The interagency group noted several limitations to the SCC analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes the interagency modeling exercise even more difficult. The interagency group hopes that over time researchers and modelers will work to fill these gaps and that the SCC estimates the Federal Government uses for regulatory analysis will continue to evolve with improvements in modeling. Additional details on these limitations are discussed in the SCC TSD.

Although CO_2 is the most prevalent GHG emitted into the atmosphere, other GHGs, including CH_4, N_2O, HFC, PFC, and SF_6, also contribute to climate change. However, because these gases differ in atmospheric lifetimes, their relative damages are not constant over time. For example, because CH_4 has a short life, its impacts occur primarily in the near term and are not discounted as heavily as those caused by longer-lived gases. Therefore, transforming gases into CO_2 equivalents using GWP and multiplying the carbon equivalents by the SCC would not result in accurate estimates of the social costs of non-CO_2 gases; the SCC estimates used in this analysis account only for the effects of changes in CO_2 emissions.

Although the SCC analysis omits the effects of changes in non-CO_2 GHG emissions, most of the emission reductions for this Proposed Action are for CO_2. Given the broad range in the values of SCC used in this EIS, omitting the other GHGs is not a barrier to distinguishing among alternatives.

5.3.3 Methodology for Estimating Climate Effects

This EIS estimates and reports four effects of climate change driven by alternative scenarios of projected changes in GHG emissions:

1. Changes in CO_2 concentrations
2. Changes in global temperature
3. Changes in precipitation
4. Changes in sea level

The change in GHG emissions is a direct effect of the improvements in fuel efficiency associated with the alternatives; the four effects on climate change can be considered indirect effects.

This EIS uses a simple climate model to estimate the changes in CO_2 concentrations, global mean surface temperature, and changes in sea level for each alternative, and uses increases in global mean surface temperature combined with an approach and coefficients from the IPCC Fourth Assessment Report (IPCC 2007a) to estimate changes in global precipitation. NHTSA used the publicly available modeling software MAGICC 5.3.v2 (Wigley 2008) to estimate changes in key direct and indirect effects. NHTSA used MAGICC 5.3.v2 to incorporate the estimated reductions in emissions of CO_2, CH_4, N_2O, CO, NO_x, SO_2, and VOCs produced by the Volpe model (tailpipe) and the associated reductions in upstream emissions estimated using GREET. NHTSA also performed a sensitivity analysis to examine variations in the direct and indirect climate impacts of the action alternatives under different assumptions about the sensitivity of climate to GHG concentrations in Earth's atmosphere. The results of the sensitivity analysis can be used to infer how the variation in GHG emissions associated with the action alternatives affects the anticipated magnitudes of direct and indirect climate impacts.

Section 5.3.3.1 through 5.3.3.3 describe MAGICC, the climate sensitivity analysis, and the baseline emissions scenario used to represent the No Action Alternative in this analysis.

5.3.3.1 MAGICC Version 5.3.v2

The selection of MAGICC for this analysis was driven by several factors, as follows:

- MAGICC has been used in the peer-reviewed literature to evaluate changes in global mean surface temperature and sea-level rise. Past applications include the IPCC Fourth Assessment Report for Working Group I (WGI) (IPCC 2007a), where it was used to estimate global mean surface temperature and sea-level rise for simulations of global emission scenarios that were not run with the more complex atmospheric-ocean general circulation models (AOGCMs).[28]
- MAGICC is publicly available and was designed for the type of analysis performed in this EIS.
- More complex AOGCMs are not designed for the type of sensitivity analysis performed here, and are best used to provide results for groups of scenarios with much greater differences in emissions.
- MAGICC has been updated to version 5.3.v2 to incorporate the science from the IPCC Fourth Assessment Report (Wigley 2008).
- EPA is also using MAGICC 5.3.v2 for its Draft RIA.
- NHTSA used MAGICC to assess direct and indirect impacts of climate change in the Final EIS for the MY 2012–2016 CAFE standards released in February 2010 (NHTSA 2010b) and again for the MY 2014–2018 HD Final EIS released in June 2011 (NHTSA 2011b).

5.3.3.2 Global Emission Scenarios

As described above, MAGICC uses long-term emission scenarios representing different assumptions about key drivers of GHG emissions. The reference scenario is the GCAM (formerly MiniCAM) reference scenario (i.e., it does not assume a comprehensive global policy to mitigate GHG emissions) used as the basis for the RCP4.5 scenario (Thomson et al. 2011). This scenario is used because it contains a comprehensive suite of greenhouse and pollutant gas emissions, including carbonaceous aerosols. The GCAMReference scenario provides a global context for emissions of a full suite of GHGs and ozone precursors.

The GCAMReference scenario is based on scenarios presented in Clarke et al. (2007). It uses non-CO_2 and pollutant gas emissions implemented as described in Smith and Wigley (2006); land use change emissions as described in Wise et al. (2009); and updated base-year estimates of global GHG emissions. This scenario was created as part of the Climate Change Science Program effort to develop a set of long-term (2000 to 2100) global emission scenarios that incorporate an update of economic and technology data and use improved scenario development tools compared to the IPCC *Special Report on Emissions Scenarios* (SRES) (IPCC 2000) developed more than a decade ago.

Strategic Plan for the U.S. Climate Change Science Program (CCSP 2003) called for the preparation of 21 synthesis and assessment products, and noted that emissions scenarios are essential for comparative analysis of future climate change and for analyzing options for mitigating and adapting to climate change. The plan includes Product 2.1, *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations and Review of Integrated*

[28] For a discussion of AOGCMs, *see* Chapter 8 in IPCC 2007a.

Scenario Development and Application (Clarke et al. 2007), which presents 15 scenarios, 5 from each of the 3 modeling groups (IGSM, MiniCAM, and MERGE).[29]

Each climate modeling group independently produced a unique emission reference scenario based on the assumption that no climate policy would be implemented beyond the current set of policies in place using a set of assumptions about drivers such as population changes, economic growth, land and labor productivity growth, technological options, and resource endowments. In addition, each group produced four additional stabilization scenarios, which are defined in terms of the total long-term radiative impact of the suite of GHGs that includes CO_2, N_2O, CH_4, HFCs, PFCs, and SF_6. These stabilization scenarios represent various levels of implementation of global GHG emissions reduction policies.

While the direct and indirect impacts analysis used the GCAMReference scenario, the cumulative impacts analysis used the GCAM6.0 scenario to represent a Reference Case global emission scenario. Sections 5.3.3.2.1 through 5.3.3.2.3 describe the differences among these scenarios and provide the rationale for use in each analysis.

5.3.3.2.1 Scenario Used for the Direct and Indirect Impacts Analysis

The results of the direct and indirect impacts analysis rely primarily on the GCAMReference scenario (which is based on the MiniCAM reference scenario developed for SAP 2.1) to represent a reference case emissions scenario; that is, future global emissions assuming no additional climate policy. To model the results of the direct and indirect effects analysis, NHTSA chose the GCAMReference scenario based on the following factors:

- The GCAMReference scenario is a slightly updated version of the scenario developed by the MiniCAM model of the Joint Global Change Research Institute, which is a partnership between Pacific Northwest National Laboratory and the University of Maryland. The GCAMReference scenario is based on a set of assumptions about drivers such as population, technology, and socioeconomic changes, in the absence of global action to mitigate climate change.[30]
- In terms of global emissions of CO_2 from fossil fuels and industrial sources, the GCAMReference scenario is an updated version of the MiniCAM model scenario and illustrates a pathway of emissions between the IGSM and MERGE reference scenarios for most of the twenty-first century. In essence, the GCAMReference scenario is a "middle-ground" scenario.
- SAP 2.1 is more than a decade newer than the IPCC SRES, and therefore has updated economic and technology data and assumptions and uses improved integrated assessment models that account for advances in economics and science over the past 10 years.

[29] IGSM is the Massachusetts Institute of Technology Integrated Global System Model. MERGE is Model for Evaluating the Regional and Global Effects of GHG Reduction Policies developed jointly by Stanford University and the Electric Power Research Institute.
[30] As described in Thomson et al. (2011), "The GCAM reference scenario depicts a world in which global population reaches a maximum of more than 9 billion in 2065 and then declines to 8.7 billion in 2100 while global GDP grows by an order of magnitude and global energy triples. The reference scenario includes no explicit policies to limit carbon emissions, and therefore fossil fuels continue to dominate global energy consumption, despite substantial growth in nuclear and renewable energy."

EPA also used the GCAMReference scenario for the Regulatory Impact Analysis for the joint NHTSA and EPA *Final Rule on Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles*.[31]

The GCAMReference scenario provides a global context for emissions of a full suite of GHGs and ozone precursors. There are some inconsistencies between the overall assumptions that SAP 2.1 and the Joint Global Change Research Institute used to develop the global emissions scenario and the assumptions used in the Volpe model in terms of economic growth, energy prices, energy supply, and energy demand.[32] However, these inconsistencies affect the characterization of each alternative in equal proportion, so the relative estimates provide a reasonable approximation of the differences in environmental impacts among the alternatives.

As noted above, each alternative was simulated by calculating the difference between annual GHG emissions under that alternative and emissions under the No Action Alternative, and subtracting this change from the GCAMReference scenario to generate modified global-scale emissions scenarios, which show the effects of the various regulatory alternatives on the global emissions path.[33] For example, CO_2 emissions from passenger cars and light trucks in the United States in 2020 under the No Action Alternative in Analysis A are 1,402 $MMTCO_2$; the emissions in 2020 under the Preferred Alternative in Analysis A are 1,370 $MMTCO_2$ (*see* Table 5.4.1-2-A). The difference of 32 $MMTCO_2$ represents the reduction in emissions projected to result from adopting the Preferred Alternative under Analysis A. Global emissions for the GCAMReference scenario in 2020 are 38,017 $MMTCO_2$, and are assumed to incorporate emissions from passenger cars and light trucks in the United States under the No Action Alternative. Global emissions under the Preferred Alternative are therefore estimated to be 32 $MMTCO_2$ less than this reference level, or approximately 37,985 $MMTCO_2$ in 2020.

5.3.3.2.2 Scenarios Used for the Cumulative Impacts Analysis

The results for cumulative impacts rely primarily on the GCAM6.0 scenario to represent a Reference Case global emissions scenario; that is, future global emissions assuming significant global actions to address climate change.[34] This Reference Case global emissions scenario serves as a baseline against which the climate benefits of the various alternatives in this EIS

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[31] *See* EPA's Final Regulatory Impact Analysis, Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, August 2011, *Available at:* <http://www.epa.gov/otaq/climate/regulations.htm> (*Accessed:* November 11, 2011).

[32] Many of the economic assumptions used in the Volpe model (e.g., vehicle miles traveled, freight miles, and freight modal shares) reflect the assumptions and methodologies described in Chapter 2.

[33] The GCAMReference is a reference baseline well established in the scientific community. While it would be possible to adjust this baseline based on recent rulemakings for MY 2012–2016 CAFE standards and MY 2014–2018 HD vehicle standards, NHTSA has not done so because this would suggest that the agency should also speculate about how other recent domestic and global actions might have affected this baseline. Adjusting this baseline in such a manner would undermine the integrity of a well-established reference point and would have little effect on the magnitude of the impacts attributed to the rule in terms of the climate parameters.

[34] The RCP4.5 scenario is another, more aggressive, stabilization scenario that illustrates the climate system response to stabilizing the anthropogenic components of radiative forcing at 4.5 watts per square meter in 2100. The RCP4.5 scenario "assumes that climate policies, in this instance the introduction of a set of global greenhouse gas emissions prices, are invoked to achieve the goal of limiting emissions, concentrations and radiative forcing" (Thomson et al. 2011). This scenario is a "stabilization scenario" – i.e., one that stabilizes the atmospheric concentration of CO_2 – with a pathway that minimizes cost. In other words, the RCP4.5 scenario "assumes that all nations of the world undertake emissions mitigation simultaneously and effectively, and share a common global price that all emissions to the atmosphere must pay with emissions of different gases priced according to their hundred-year global warming potentials" (Thomson et al. 2011). Although RCP4.5 does not explicitly include specific climate change mitigation policies, it represents a plausible future pathway of global emissions in response to more significant global action to mitigate climate change than the GCAM6.0 scenario.

can be measured. NHTSA chose the GCAM6.0 scenario to represent reasonably foreseeable actions.

The GCAM6.0 scenario is the GCAM representation of the radiative forcing target (6.0 watts per square meter) of the RCP scenarios developed by the MiniCAM model of the Joint Global Change Research Institute, which is a partnership between Pacific Northwest National Laboratory and the University of Maryland. The GCAM6.0 scenario assumes a moderate level of global GHG reductions. It is based on a set of assumptions about drivers such as population, technology, socioeconomic changes, and global climate policies that correspond to stabilization, by 2100, of total radiative forcing and associated CO_2 concentrations at roughly 678 parts per million by volume (ppm).[35] More specifically, GCAM6.0 is a scenario that incorporates declines in overall energy use, including fossil fuel use, as compared to the reference case. In addition, GCAM6.0 includes increases in renewable energy and nuclear energy, with the proportion of electricity-supplied total final energy increasing due to fuel switching in the end-use sectors. CO_2 capture and storage also plays an important role that allows for continued use of fossil fuels for electricity generation and cement manufacture while limiting CO_2 emissions. Although GCAM6.0 does not explicitly include specific climate change mitigation policies, it does represent a plausible future pathway of global emissions in response to significant global action to mitigate climate change. GCAM scenarios were developed more than 10 years after the IPCC SRES, and therefore include updated economic and technology data/assumptions. GCAM scenarios also use improved integrated assessment models that account for advances in economics and science over the past 10 years.

As an example of how regulatory or policy actions can affect the global emission baseline, the MY 2012–2016 CAFE standards are estimated to reduce GHG emissions by 32,300 $MMTCO_2$. These emission reductions would, in turn, reduce by 2100: (1) the growth in atmospheric CO_2 concentrations by 3.1 ppm, (2) the increase in global mean surface temperature by 0.012 °C (0.22 °F), and (3) the rise in sea level by 0.10 centimeters (0.039 inch) over the same period. As another example, the recently enacted MY 2014–2018 HD vehicle standards will decrease GHG emissions by 1,400 $MMTCO_2$, producing a reduction in growth of atmospheric CO_2 concentration by 0.13 ppm and a decrease in sea-level rise of roughly 0.01 centimeters (0.0039 inch) with respect to projected levels in the year 2100.

NHTSA used the GCAM6.0 scenario as the primary global emission scenario for evaluating climate effects, but also used the RCP4.5 scenario and the GCAMReference emission scenario (an updated version of the MiniCAM model scenario) to evaluate the sensitivity of the results to alternative emission scenarios.

Separately, each action alternative for cumulative impacts was simulated by calculating the difference between annual GHG emissions under that alternative and emissions under the No Action Alternative and subtracting this change in the GCAM6.0 scenario to generate modified global-scale emissions scenarios, which show the effect of the various alternatives on the global emissions path. For example, cumulative emissions from passenger cars and light trucks in the United States in 2020 under the No Action Alternative are 1,402 $MMTCO_2$; emissions in 2020 under the Preferred Alternative are 1,366 $MMTCO_2$ (*see* Table 5.4.2-2). The difference of 36 $MMTCO_2$ (rounded) represents the reduction in emissions projected to result from adopting the Preferred Alternative. Global CO_2 emissions for the GCAM6.0 scenario in 2020 are 37,522 $MMTCO_2$ and are assumed to incorporate the level of emissions from passenger cars and light trucks in the United States under the No Action Alternative. Global emissions under the

[35] Based on 3 °C (5.4 °F) climate sensitivity.

Preferred Alternative are therefore estimated to be 36 $MMTCO_2$ less than this reference level, or 37,486 $MMTCO_2$ in 2020 under the cumulative impacts analysis.

For this analysis, despite the inconsistencies between the GCAM assumptions on global trends across all GHG-emitting sectors (and the drivers that affect them) and the particularities of the emission estimates for the U.S. transportation sector provided by the Volpe model, the approach used is valid. These inconsistencies affect all alternatives equally, and therefore do not hinder a comparison of the alternatives in terms of their relative effects on climate.

5.3.3.2.3 Past, Present, and Reasonably Foreseeable Future Actions Related to the Cumulative Impacts Analysis

NHTSA chose the GCAM6.0 scenario as the primary global emissions scenario for evaluating climate effects for this chapter, because regional, national, and international initiatives and programs now in the planning stages and underway indicate that some reduction in the rate of global GHG emissions is reasonably foreseeable in the future. The initiatives and programs discussed below are those NHTSA has tentatively concluded are past, present, or reasonably foreseeable actions to reduce GHG emissions. Although it is not possible to quantify the precise GHG reductions associated with these actions, policies, or programs when taken together, collectively they illustrate an existing and continuing trend of U.S. and global awareness, emphasis, and efforts toward significant GHG reductions. NHTSA has not attempted to quantify the precise benefits associated with these programs. Rather, they imply that future commitments for reductions are probable and, therefore, a scenario that accounts for moderate reductions in the rate of global GHG emissions, such as the GCAM6.0 scenario, can be considered reasonably foreseeable under NEPA.

United States: Regional Actions

- **Regional Greenhouse Gas Initiative (RGGI).** Beginning January 1, 2009, RGGI was the first mandatory, market-based effort in the United States to reduce GHG emissions (RGGI 2009). Ten northeastern and Mid-Atlantic States (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey,[36] New York, Rhode Island, and Vermont) agreed to cap annual emissions from power plants in the region at 188 $MMTCO_2$ (RGGI 2009). Beginning in 2015, this cap will be reduced 2.5 percent each year through 2019, for a total of a 10 percent emission reduction from the 2015 cap from the power sector by 2018 (RGGI 2009, 2011). Therefore, the cap comprises two phases: the first is a stabilization phase from 2009 through 2014, and the second is a reduction phase from 2015 through 2018.
- **Western Climate Initiative (WCI).** The WCI includes 7 partner States (Arizona, California, Montana, New Mexico, Oregon, Utah, and Washington) and 4 partner Canadian provinces (British Columbia, Manitoba, Ontario, and Quebec), along with 16 additional observer states or provinces in the United States, Canada, and Mexico (not currently active participants). Set to begin on January 1, 2012, the WCI cap-and-trade program will cover emissions of the six main GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) from the following sectors of the economy: electricity generation, including imported electricity; industrial and commercial fossil-fuel combustion; industrial process emissions; gas and diesel consumption for transportation; and residential fuel use. Affected entities and facilities will be required to surrender enough allowances to cover emissions that occur within each 3-year "compliance period." This multi-sector program is the most comprehensive carbon-reduction strategy

[36] In 2011, the Governor of New Jersey stated his intent to withdraw New Jersey from RGGI by the end of 2011.

designed to date in the United States. This program is an important component of the WCI comprehensive regional effort to reduce GHG emissions to 15 percent below 2005 levels by 2020. The program will be rolled out in two phases. The first phase will begin on January 1, 2012, and will cover emissions from electricity, including imported electricity, industrial combustion at large sources, and industrial process emissions for which adequate measurement methods exist. Not all WCI states are planning to participate in the first phase, but approximately two-thirds of all jurisdictional emissions are estimated to be covered (WCI 2010). The second phase begins in 2015, when the program expands to include transportation fuels and residential, commercial, and industrial fuels not otherwise covered (WCI 2010). When fully implemented in 2015, the program will cover nearly 90 percent of GHG emissions in the 11 WCI partner states and provinces.

United States: Federal Actions

- **NHTSA and EPA Joint Rule on Fuel Economy and GHG Emissions Standards for Light-Duty Vehicles.** In April 2010, NHTSA and EPA issued a joint Final Rule establishing a new National Program to regulate MY 2012–2016 passenger cars and light trucks to improve fuel efficiency and reduce GHG emissions. NHTSA issued CAFE standards under the Energy Policy and Conservation Act (EPCA), as amended by the Energy Independence and Security Act (EISA), and EPA issued GHG emissions standards under the Clean Air Act (CAA). These rules require a combined average fleetwide fuel economy of 34.1 mpg and 250 grams per mile of CO_2 for MY 2016 light-duty vehicles. Vehicles covered by these standards are responsible for almost 60 percent of all U.S. transportation-related GHG emissions. The program is projected to reduce GHG emissions from the U.S. light-duty vehicle fleet by 19 percent by 2030 (NHTSA 2010b citing EPA 2009).
- **NHTSA and EPA Joint Rule on Fuel Efficiency and GHG Emissions Standards for Medium- and Heavy-Duty Vehicles, MYs 2014–2018.** On August 9, 2011, NHTSA and EPA announced joint rules to establish fuel efficiency and GHG standards for medium- and heavy-duty engines and vehicles. The rules together comprise a coordinated and comprehensive heavy-duty vehicle National Program and result in substantial improvements in fuel efficiency and reductions in GHG emissions from heavy-duty vehicles, based on technology that is, for the most part, already being commercially applied and can be incorporated at a reasonable cost. The agencies' standards apply to highway vehicles and engines that are not regulated by the passenger car, light-duty truck, and medium-duty passenger vehicle CAFE and GHG standards. NHTSA set mandatory standards for heavy-duty vehicles and engines beginning in MY 2016 and voluntary standards beginning in MYs 2014–2015. EPA set mandatory standards for heavy-duty vehicles and engines beginning in MY 2014. The agencies estimate that the combined standards will reduce CO_2 emissions by approximately 270 million metric tons and save 530 million barrels of oil over the life of vehicles sold during MYs 2014–2018.[37]
- **EPA Prevention of Significant Deterioration (PSD) and Title V Greenhouse Gas Tailoring Rule.** In May 2010, EPA issued a rule to address GHG emissions from stationary sources under CAA permitting programs. Under the first step to phase in this rule, which went into effect January 2, 2011, only those sources already subject to the PSD program due to their non-GHG emissions (which includes newly constructed facilities or those that are modified to significantly increase non-GHG emissions) are subject to PSD and Title V permitting requirements. During the first step, such facilities that have emissions increases of at least 75,000 tons per year of GHGs (based on CO_2e), and also significantly increase

[37] Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final Rules, 76 FR 57106 (September 15, 2011).

emissions of at least one non-GHG pollutant, will need to implement Best Available Control Technology (BACT). Also during this step, no sources are subject to permitting requirements based solely on their GHG emissions. The second step, which began July 1, 2011, covers all new facilities with the potential to emit at least 100,000 tons per year of CO_2e and modifications to existing facilities that result in emissions of at least 100,000 tons per year and that increase GHG emissions by at least 75,000 tons per year of CO_2e. Title V requirements will apply to facilities that emit at least 100,000 tons per year of CO_2e. Additionally, any modifications of existing facilities that result in increases of GHG emissions of at least 75,000 tons per year will be subject to permitting requirements. EPA announced an intention to propose a rulemaking for facilities with emissions of at least 50,000 tons per year no later than July 1, 2012. This rulemaking will consider an additional step (step three) for phasing in rulemaking. This third step would begin by July 1, 2013. EPA will consider streamlining the permitting procedure and might consider whether smaller sources can be permanently excluded from permitting requirements. EPA has stated that this third step will not apply to sources with GHG emissions below 50,000 tons per year and that the agency will not issue requirements for smaller sources until April 30, 2016.

- **Renewable Fuel Standard 2 (RFS2).** Section 211(o) of the CAA requires that a renewable fuel standard be determined annually that is applicable to refiners, importers, and certain blenders of gasoline. On the basis of this standard, each obligated party determines the volume of renewable fuel that it must ensure is consumed as motor vehicle fuel. RFS2, which went into effect July 1, 2010, will increase the volume of renewable fuel required to be blended into gasoline from the baseline of 9 billion gallons in 2008 to 36 billion gallons by 2022.[38] EPA estimates that the greater volume of biofuel mandated by RFS2 will reduce life-cycle GHG emissions by an annual average of 150 million tons of CO_2e.[39] The renewable fuel standard proposed for 2012 is 9.21 percent.[40]

  United States GHG Emissions Target in Association with the Copenhagen Accord. Building on the pledge made at the December 2009 United Nations climate change conference in Copenhagen (COP-15), President Obama submitted to the United Nations Framework Convention on Climate Change (UNFCCC) a GHG target for the United States in the range of 17 percent below 2005 levels by 2020. This target is contingent on passage of U.S. energy and climate legislation. Recent federal actions that are expected to reduce GHG emissions include a $90-billion investment in clean energy through the American Recovery and Reinvestment Act of 2009, more stringent energy efficiency standards for commercial and residential appliances, and development of wind energy on the Outer Continental Shelf, among other federal initiatives.

International Actions

- **United Nations Framework Convention on Climate Change – The Kyoto Protocol, and the December 2010 Conference of the Parties (COP)-16.** UNFCCC is an international treaty signed by many countries around the world (including the United States[41]), which

[38] Final Rule: Regulations of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program. 75 FR 14670 (Mar. 26, 2010).
[39] Id.
[40] Regulation of Fuels and Fuel Additives: 2012 Renewable Fuel Standards; Proposed Rule. 76 FR 38844 (July 1, 2011).
[41] Although a signatory to the Kyoto Protocol, the United States has neither ratified nor withdrawn from the protocol. Treaties are nonbinding on the United States unless ratified by the Senate by a two-thirds majority, and the Kyoto Protocol has not been submitted to the Senate for ratification. On July 25, 1997, before the Kyoto Protocol was finalized, the Senate passed (by a 95 to 0 vote) the Byrd-Hagel Resolution, which stated the Senate position that the United States should not be a signatory to any treaty that did not include binding targets and timetables for

entered into force on March 21, 1994, and sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change (UNFCCC 2002). The Kyoto Protocol is an international agreement linked to the UNFCCC. The major feature of the Kyoto Protocol is its binding targets for 37 industrialized countries and the European Community for reducing GHG emissions, which covers more than half of the world's GHG emissions. These amount to an average of 5 percent of 1990 levels over the 5-year period 2008 through 2012 (UNFCCC 2005). For the first time, at COP-15 (held in 2009) all major developed and developing countries agreed to pledge specific emission reductions. At COP-16, in December 2010, a draft accord pledged to limit global temperature increase to less than 2 °C (3.6 °F) above pre-industrial global average temperature. As of August 1, 2011, 141 countries have agreed to the Copenhagen Accord, accounting for the vast majority of global emissions (UNFCCC 2010); the pledges, however, are not legally binding, and much remains to be negotiated.

- **The European Union Greenhouse Gas Emission Trading System (ETS).** In January 2005, the European Union ETS commenced operation as the largest multi-country, multi-sector GHG emission trading system worldwide (European Union 2010). The aim of the ETS is to help European Union member states achieve compliance with their commitments under the Kyoto Protocol (European Union 2005). This trading system does not entail new environmental targets; instead, it allows for less expensive compliance with existing targets under the Kyoto Protocol. The scheme is based on Directive 2003/87/EC, which entered into force on October 25, 2003 (European Union 2010) and covers more than 11,500 energy-intensive installations across the European Union, which represent almost half of Europe's emissions of CO_2. These installations include combustion plants, oil refineries, coke ovens, and iron and steel plants, and factories making cement, glass, lime, brick, ceramics, pulp, and paper (European Union 2005).
- **G8 Declaration – Summit 2010.** During the June 2010 G8 Summit in Canada, the G8 Nations officially reiterated their support of the Copenhagen Accord and urged countries that had not already signed on to associate themselves with the accord and its goals. The G8 summit officially recognized a goal that the global temperature should not increase by more than 2 °C (3.6 °F). A statement was made supporting a fair but binding post-2012 agreement for all countries to reduce their GHG emissions.

5.3.3.3 Reference Case Modeling Runs

The modeling runs and sensitivity analysis are designed to use information on the alternatives, climate sensitivities, and the global emissions scenario (Thomson et al. 2011)[42] to model relative changes in atmospheric concentrations, global mean surface temperature, precipitation, and sea-level rise that could result under each alternative.

The modeling runs are based on the reductions in emissions estimated to result from each of the action alternatives for both the direct and indirect and cumulative impacts analyses, assuming a climate sensitivity of 3 °C (5.4 °F) for a doubling of CO_2 concentrations in the atmosphere, and the global emissions scenario as described below.

developing nations as well as industrialized nations or "would result in serious harm to the economy of the United States." *See* S. Res. 98, 105th Cong. (1997).

[42] The use of different emission scenarios provides insight into the impact of alternative global emission scenarios on the effect of the CAFE alternatives.

The approach uses the following four steps to estimate these changes:

1. NHTSA assumed that global emissions under the No Action Alternative follow the trajectory provided by the global emissions scenario.
2. NHTSA assumed that global emissions for each action alternative are equal to the global emissions under the No Action Alternative minus the reductions in emissions of CO_2, CH_4, N_2O, SO_2, NO_x, CO, and VOCs estimated to result from each action alternative (for example, the global emissions scenario under Alternative 2 equals the global emissions scenario minus the emission reductions from that alternative). All SO_2 reductions were applied to the Aerosol region 1 of MAGICC, which includes North America.
3. NHTSA used MAGICC 5.3.v2 to estimate the changes in global CO_2 concentrations, global mean surface temperature, and sea-level rise through 2100 using the global emissions scenario under each alternative developed in steps 1 and 2.
4. NHTSA used the increase in global mean surface temperature, along with factors relating the increase in global average precipitation to this increase in global mean surface temperature, to estimate the increase in global average precipitation for each alternative using the global emission scenario.

Section 5.4 presents the results of the sensitivity model runs for the alternatives.

The cumulative impacts (Section 5.4.2) climate analysis is broader than the corresponding direct and indirect impacts analysis (Section 5.4.1) because cumulative impacts address the effects of the proposed MY 2017–2025 CAFE standards together with those of past, present, and reasonably foreseeable future actions.

5.3.3.4 Sensitivity Analysis

NHTSA performed a sensitivity analysis to examine the effect of various equilibrium climate sensitivities on the results. Equilibrium climate sensitivity[43] is the projected responsiveness of Earth's global climate system to increased radiative forcing from higher GHG concentrations, and is expressed in terms of changes to global surface temperature resulting from a doubling of CO_2 in relation to pre-industrial atmospheric concentrations (280 ppm CO_2) (EPA 2009e citing NRC 2001). In the past 8 years, confidence in climate sensitivity projections has increased significantly (EPA 2009e citing Meehl et al. 2007). According to the IPCC, with a doubling of the concentration of atmospheric CO_2, there is a *likely* probability of an increase in surface warming of 2.0 to 4.5 °C (3.6 to 8.1 °F), and a *very likely* probability of an increase of 1.5 to 6.0 °C (2.7 to 10.8 °F), with a best estimate of 3 °C (5.4 °F) (IPCC 2007a, EPA 2009e, Meehl et al. 2007).

NHTSA assessed climate sensitivities of 1.5, 2.0, 2.5, 3.0, 4.5, and 6.0 °C (2.7, 3.6, 4.5, 5.4, 8.1, and 10.8 °F) for a doubling of CO_2 concentrations in the atmosphere. NHTSA performed the sensitivity analysis around two of the alternatives – the No Action Alternative and the Preferred Alternative – because this was deemed sufficient to assess the effect of various climate sensitivities on the results.

The approach uses the four steps listed below to estimate the sensitivity of the results to alternative estimates of the climate sensitivity

[43] In this EIS, the term "climate sensitivity" refers to "equilibrium climate sensitivity."

1. NHTSA used the GCAMReference scenario for the direct and indirect impacts analysis, and the GCAM6.0 scenario in the cumulative impacts analysis to represent emissions from the No Action Alternative.
2. Starting with the respective GCAM scenario, NHTSA assumed that the reductions in global emissions of CO_2, CH_4, N_2O, SO_2, NO_x, CO, and VOCs resulting from the Preferred Alternative are equal to the global emissions of each pollutant under the No Action Alternative minus emissions of each pollutant under the Preferred Alternative. All SO_2 reductions were applied to Aerosol region 1 of MAGICC, which includes North America.
3. NHTSA assumed a range of climate sensitivity values consistent with the 10 to 90 percent probability distribution from the IPCC Fourth Assessment Report (IPCC 2007a) of 1.5, 2.0, 2.5, 3.0, 4.5, and 6.0 °C (2.7, 3.6, 4.5, 5.4, 8.1, and 10.8 °F).[44]
4. For each climate sensitivity value in step 3, NHTSA used MAGICC 5.3.v2 to estimate the resulting changes in CO_2 concentrations, global mean surface temperature, and sea-level rise through 2100 for the global emissions scenarios in steps 1 and 2.

Section 5.4 presents the results of the model runs for the alternatives.

Sensitivity analyses examine the relationship among the alternatives, likely climate sensitivities, and scenarios of global emissions paths and the associated direct and indirect impacts for each combination. These relationships can be used to infer the effect of the emissions associated with the alternatives on direct and indirect climate impacts.

For the direct and indirect impacts analysis, the sensitivity analysis was performed against the GCAMReference scenario (785 ppm in 2100). For the cumulative impacts analysis, the sensitivity analysis also assesses the sensitivity around different global emissions scenarios. NHTSA assumed multiple global emissions scenarios including GCAM6.0 (678 ppm in 2100); RCP4.5 (522 ppm in 2100); and GCAMReference scenario (785 ppm in 2100). Section 5.4.2.3.5 presents the results of the cumulative impacts sensitivity analysis for these different global emission scenarios.

5.3.4 Tipping Points and Abrupt Climate Change

The phrase tipping point is most typically used, in the context of climate change and its consequences, to describe situations in which the climate system (the atmosphere, hydrosphere, land, cryosphere,[45] and biosphere) reaches a point at which a disproportionally large or singular response in a climate-affected system occurs as a result of only a moderate additional change in the inputs to that system (such as an increase in the CO_2 concentration). Exceeding one or more tipping points, which "occur when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause" (EPA 2009e citing NRC 2002), could result in abrupt changes in the climate or any part of the climate system. Abrupt climate changes could occur so quickly and unexpectedly that human systems would have difficulty adapting to them (EPA 2009e citing NRC 2002).

The methodology used to address tipping points is based on an analysis of climate change science synthesis reports – including *Technical Support Document for EPA's Endangerment Finding for GHGs* (EPA 2009e), the IPCC WGI report (Meehl et al. 2007), and CCSP SAP 3.4:

[44] *See* Box 10.2, Figure 2 in IPCC 2007a.
[45] The cryosphere describes the portion of Earth's surface that is frozen water, such as snow, permafrost, floating ice, and glaciers.

Abrupt Climate Change – and recent literature on the issue of tipping points and abrupt climate change. The analysis identifies vulnerable systems, potential thresholds, and estimates of the causes, likelihood, timing, and impacts of abrupt climate events. Although there are methodological approaches to estimate changes in temperatures resulting from a reduction in GHG emissions and associated radiative forcing, the current state of science does not allow for quantifying how emission reductions from a specific policy or action might affect the probability and timing of abrupt climate change. This area of climate science is one of the most complex and scientifically challenging; given the difficulty of simulating the large-scale processes involved in these tipping points, or inferring their characteristics from paleoclimatology, considerable uncertainties remain on tipping points and the rate of change. Despite the lack of a precise quantitative methodological approach, NHTSA has provided a qualitative and comparative analysis of tipping points and abrupt climate change in Section 5.5.8 of this EIS.[46] The analysis applies equally to the direct and indirect impacts discussion and the cumulative impacts discussion given that tipping points are best viewed in the perspective of long-term, large-scale global trends.

[46] *See* 42 U.S.C. § 4332 (requiring federal agencies to "identify and develop methods and procedures … which will insure that presently unquantified environmental amenities and values may be given appropriate consideration"); *Considering Cumulative Effects Under the National Environmental Policy Act* (CEQ 1997b) (recognizing that agencies are sometimes "limited to qualitative evaluations of effects because cause-and-effect relationships are poorly understood" or cannot be quantified).

5.4 Environmental Consequences

This section provides the projected impacts on climate under the Proposed Action. Using the methodologies described in Section 5.3, NHTSA modeled the effects of the proposed standards on atmospheric CO_2 concentrations, temperature, precipitation, and sea-level rise.

Two separate analyses were performed: one to assess the direct and indirect impacts of the Proposed Action, and one to assess the cumulative impacts. To calculate the incremental benefits of the Proposed Action, this section examines the direct and indirect impacts under the Analysis A and Analysis B methodologies described in Chapter 2 and summarized here.

- Analysis A measures the impact of action alternatives where fleetwide fuel economy after MY 2025 will never exceed the level of the MY 2025 standards, in relation to a No Action Alternative under which the light-duty vehicle fleet would attain an average fleetwide fuel economy no higher than that required under the agencies' MY 2016 standards established by final rule in April 2010. Tables and figures that depict results for Analysis A include an "A" after the table or figure number.
- Analysis B measures the impact of action alternatives assuming ongoing increases beyond the level of the MY 2025 standards in new light-duty vehicle fuel economy after MY 2025, in relation to a No Action Alternative that assumes the average fleetwide fuel economy level of light-duty vehicles would continue to increase beyond the level necessary to meet the MY 2016 standards, even in the absence of agency action. Tables and figures that depict results for Analysis B include a "B" after the table or figure number.

The direct and indirect impacts analysis (Section 5.4.1) is based on a scenario under which there are no other major global actions to reduce GHGs. It presents the projected results of the Proposed Action and alternatives in relation to the current climate trajectory, independent of other actions.

The cumulative impacts (Section 5.4.2) analysis measures the impact of fuel economy improvements that result directly or indirectly from the Proposed Action in addition to reasonably foreseeable improvements in fuel economy caused by other actors – that is, fuel economy improvements that would result from actions taken by manufacturers without the agency's action. For assessing climate impacts, the analysis in Section 5.4.2 is also broader in that it addresses the effects of the proposed standards in concert with the effects of other past, present, and reasonably foreseeable future actions affecting the current climate trajectory. *See* Section 5.3 for a description of the cumulative impacts methodology.

Separate results for passenger cars and light trucks are attached to this EIS as Appendix A.

5.4.1 Direct and Indirect Impacts

This section describes the environmental consequences of the Proposed Action and alternatives on GHG emissions and climate effects.

5.4.1.1 Greenhouse Gas Emissions

Using the methodology described in Section 5.3, projected emission reductions resulting from the Proposed Action and alternatives were estimated for 2017 through 2100. The emission reductions in the following discussion represent the differences in total annual emissions in future years of U.S. passenger cars and light trucks in use under the No Action Alternative and each action alternative (Alternatives 2 through 4). The projected change in fuel production and use under each alternative determines the resulting impacts on total energy use and petroleum consumption, which in turn determine the reduction in CO_2 emissions that result under each alternative. Because CO_2 accounts for such a large fraction of total GHGs emitted during fuel production and use – more than 95 percent, even after accounting for the higher GWPs of other GHGs – NHTSA's consideration of GHG impacts focuses on reductions in CO_2 emissions that are expected under the Proposed Action. However, in assessing the direct and indirect impacts and cumulative impacts on climate change indicators, as described in Sections 5.4.1.3 and 5.4.2.3, NHTSA incorporates reductions of all GHGs.

Table 5.4.1-1-A and Figure 5.4.1-1-A show total U.S. passenger car and light truck CO_2 emissions under the No Action Alternative and emission reductions that would result from each of the action alternatives from 2017 through 2100 for Analysis A. U.S. passenger car and light truck emissions for this period range from a low of 119,000 $MMTCO_2$ under Alternative 4 to 166,500 $MMTCO_2$ under the No Action Alternative. Compared to the No Action Alternative, projected emission reductions from 2017 through 2100 under the action alternatives range from 19,100 to 47,500 $MMTCO_2$.

Under Analysis A, compared to total global emissions of 5,099,256 $MMTCO_2$ over this period (projected by the GCAMReference scenario), the proposed rulemaking is expected to reduce global CO_2 emissions by approximately 0.4 to 0.9 percent from their projected levels under the No Action Alternative.

Table 5.4.1-1-A. CO_2 Emissions and Emission Reductions ($MMTCO_2$) from U.S. Passenger Cars and Light Trucks from 2017 through 2100 by Alternative,[a] Analysis A

Alternative	Total Emissions	Emission Reductions Compared to the No Action Alternative	Percent Emission Reductions Compared to No Action Alternative Emissions
1 - No Action	166,500		
2 - 2%/year Cars and Trucks	147,300	19,100	11%
3 - Preferred	134,300	32,200	19%
4 - 7%/year Cars and Trucks	119,000	47,500	29%

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.

Figure 5.4.1-1-A. CO_2 Emissions and Emission Reductions ($MMTCO_2$) from U.S. Passenger Cars and Light Trucks from 2017 through 2100 by Alternative, Analysis A

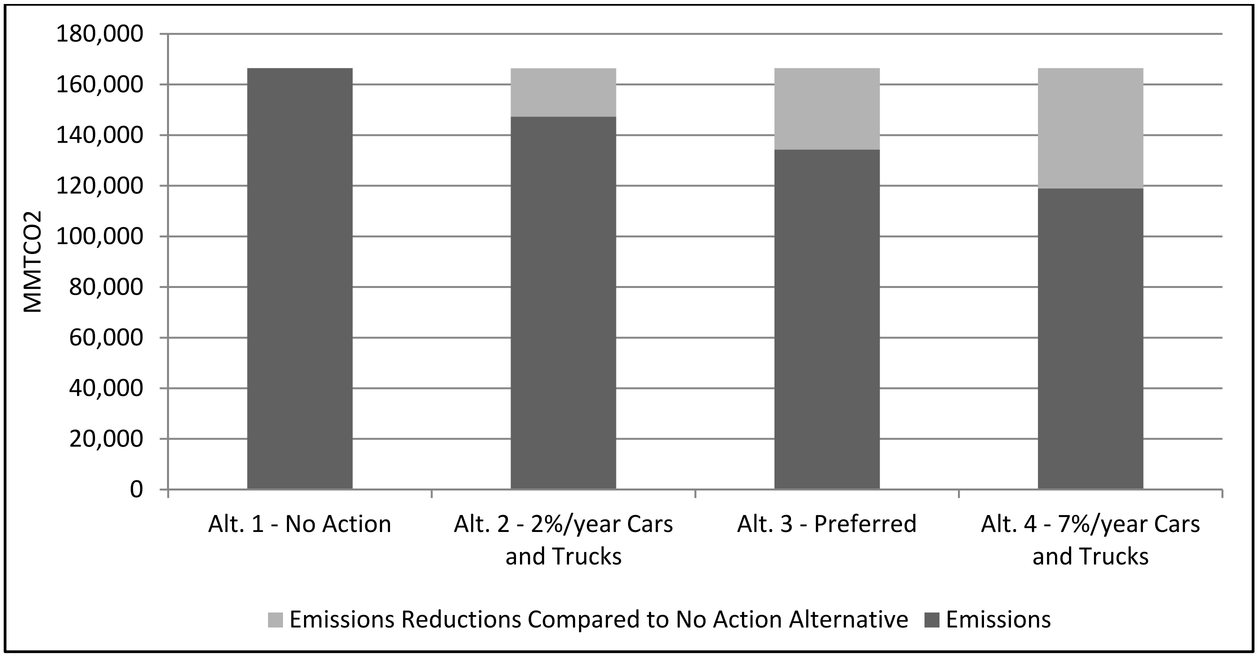


Table 5.4.1-1-B and Figure 5.4.1-1-B show total U.S. light-duty vehicle CO_2 emissions under the No Action Alternative and emission reductions that would result from each of the action alternatives from years 2017 through 2100 for Analysis B. U.S. light-duty vehicle emissions for this period range from a low of 108,200 $MMTCO_2$ under Alternative 4 to 139,500 $MMTCO_2$ under the No Action Alternative. Compared to the No Action Alternative, projections of emission reductions from 2017 through 2100 due to the action alternatives range from 8,600 to 31,300 $MMTCO_2$.

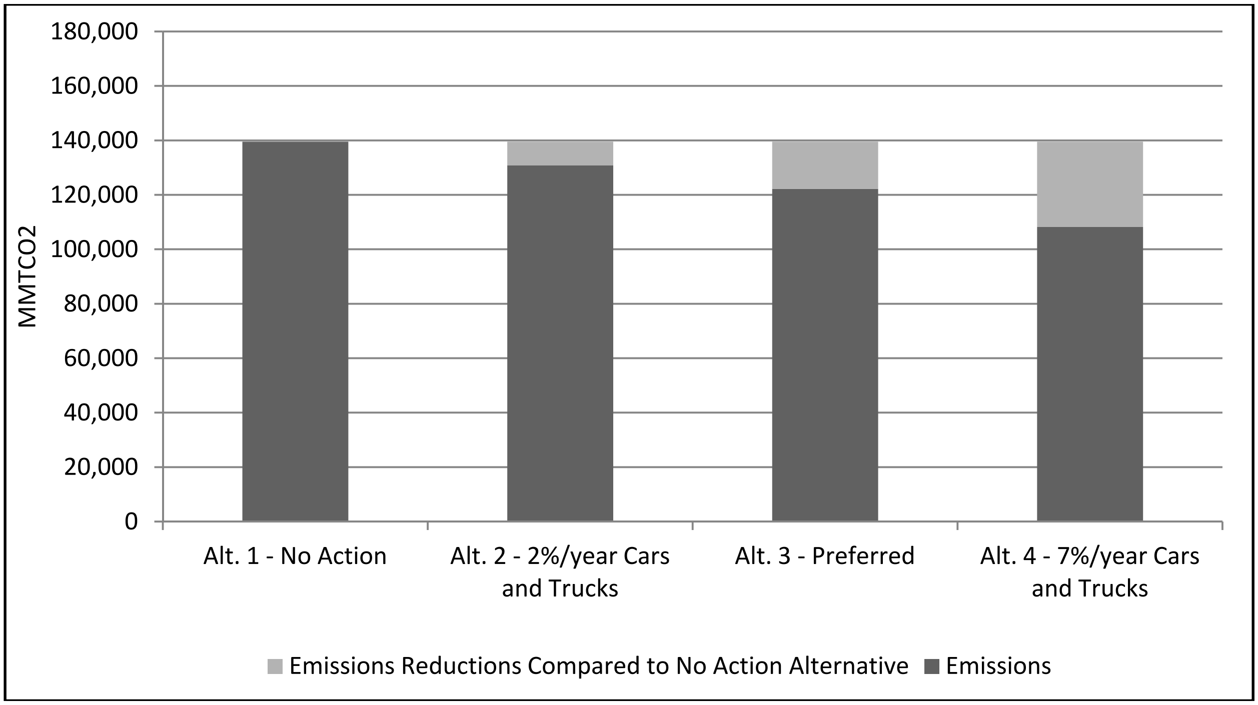
Under Analysis B, compared to total global emissions of 5,099,256 $MMTCO_2$ over this period (projected by the GCAMReference scenario), this rulemaking is expected to reduce global CO_2 emissions by about 0.2 to 0.6 percent from their projected levels under the No Action Alternative.

Table 5.4.1-1-B. CO_2 Emissions and Emission Reductions ($MMTCO_2$) from U.S. Passenger Cars and Light Trucks from 2017 through 2100 by Alternative,[a] Analysis B

Alternative	Total Emissions	Emission Reductions Compared to the No Action Alternative	Percent Emission Reductions Compared to No Action Alternative Emissions
1 - No Action	139,500		
2 - 2%/year Cars and Trucks	130,900	8,600	6%
3 - Preferred	122,200	17,300	12%
4 - 7%/year Cars and Trucks	108,200	31,300	22%

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.

Figure 5.4.1-1-B. CO_2 Emissions and Emission Reductions ($MMTCO_2$) from U.S. Passenger Cars and Light Trucks from 2017 through 2100 by Alternative, Analysis B



To get a sense of the relative impact of these reductions, it can be helpful to consider the emissions from passenger cars and light trucks in the context of emissions projections from the transportation sector and expected or stated goals from existing programs designed to reduce CO_2 emissions. Passenger cars and light trucks currently account for a significant amount of CO_2 emissions in the United States. In Analysis A, the action alternatives reduce total CO_2 emissions from light-duty vehicles by 11 to 29 percent in the period from 2017 through 2100 compared to the No Action Alternative. In Analysis B, the action alternatives reduce total CO_2 emissions from light-duty vehicles by 6 to 22 percent in the period from 2017 through 2100 compared to the No Action Alternative. Compared to total U.S. CO_2 emissions from all sources in 2100 of 7,193 $MMTCO_2$ projected by the GCAMReference scenario (Thomson et al. 2011), the action alternatives would reduce total U.S. CO_2 emissions from all sources by 3.7 to 9.2 percent under Analysis A and 1.2 to 5.3 percent under Analysis B in that year. Figures 5.4.1-2-A and 5.4.1-2-B show projected annual emissions from U.S. passenger cars and light trucks under the alternatives.

As Tables 5.4.1-2-A and 5.4.1-2-B show, under the No Action Alternative, total CO_2, CH_4, and N_2O emissions from passenger cars and light trucks in the United States are projected to increase substantially after 2020. Under each alternative analyzed, growth in the number of passenger cars and light trucks in use throughout the United States, combined with assumed increases in their average use, is projected to result in a growth in VMT. This growth in VMT more than offsets the effect of improvements in fuel economy for all alternatives (other than Alternative 4 in Analysis B), resulting in projected increases above present levels in total fuel consumption by passenger cars and light trucks in the United States over the long term. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from passenger cars and light trucks. However, the agency anticipates reduced annual fuel consumption and CO_2 emissions from present levels in the short term under these alternatives. Under Alternative 4 in Analysis B, increases in fuel economy are expected to result in fuel consumption and CO_2 emission levels through and beyond 2060 that are lower than present annual CO_2 emission levels.

Figure 5.4.1-2-A. Projected Annual CO_2 Emissions (MMTCO$_2$) from U.S. Passenger Cars and Light Trucks by Alternative, Analysis A

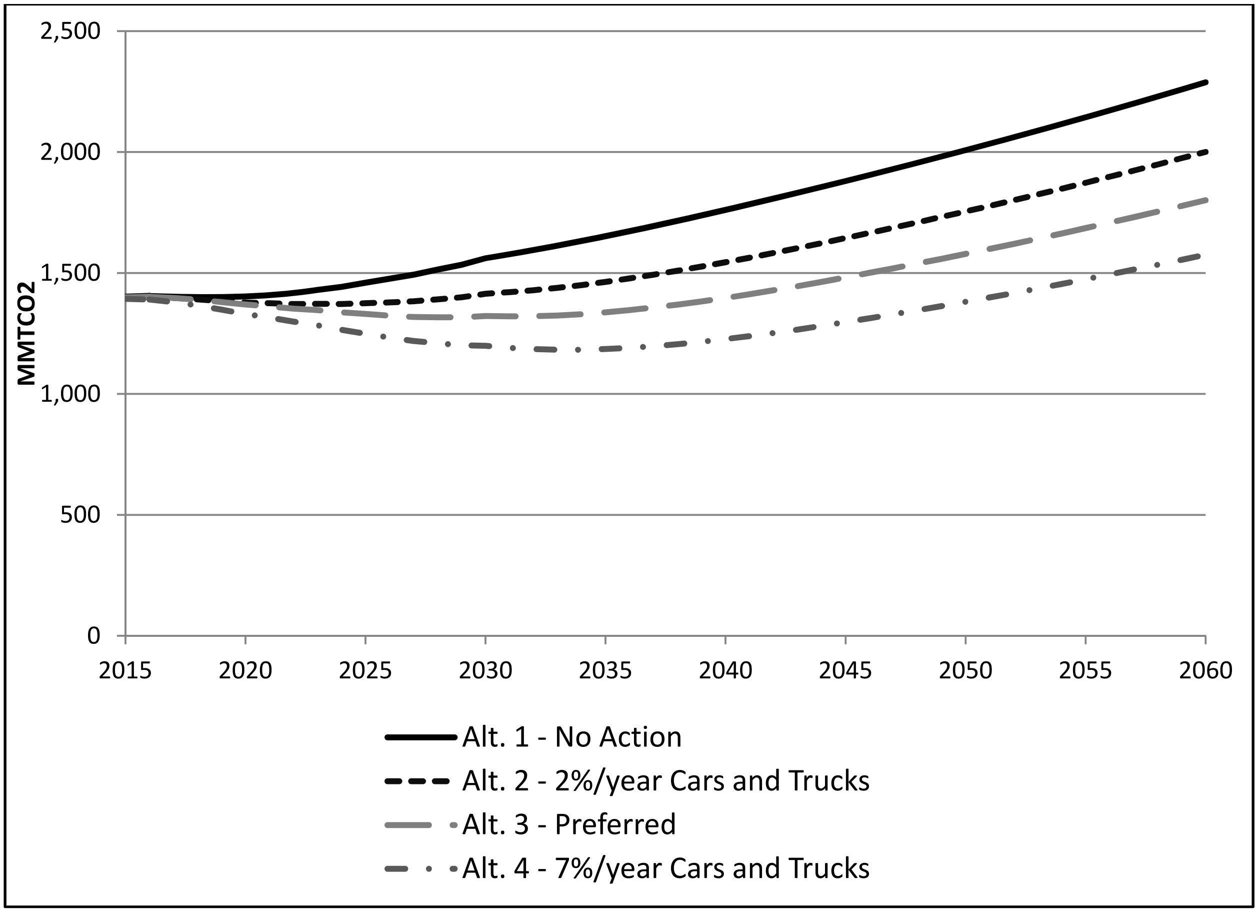


Figure 5.4.1-2-B. Projected Annual CO_2 Emissions ($MMTCO_2$) from U.S. Passenger Cars and Light Trucks by Alternative, Analysis B

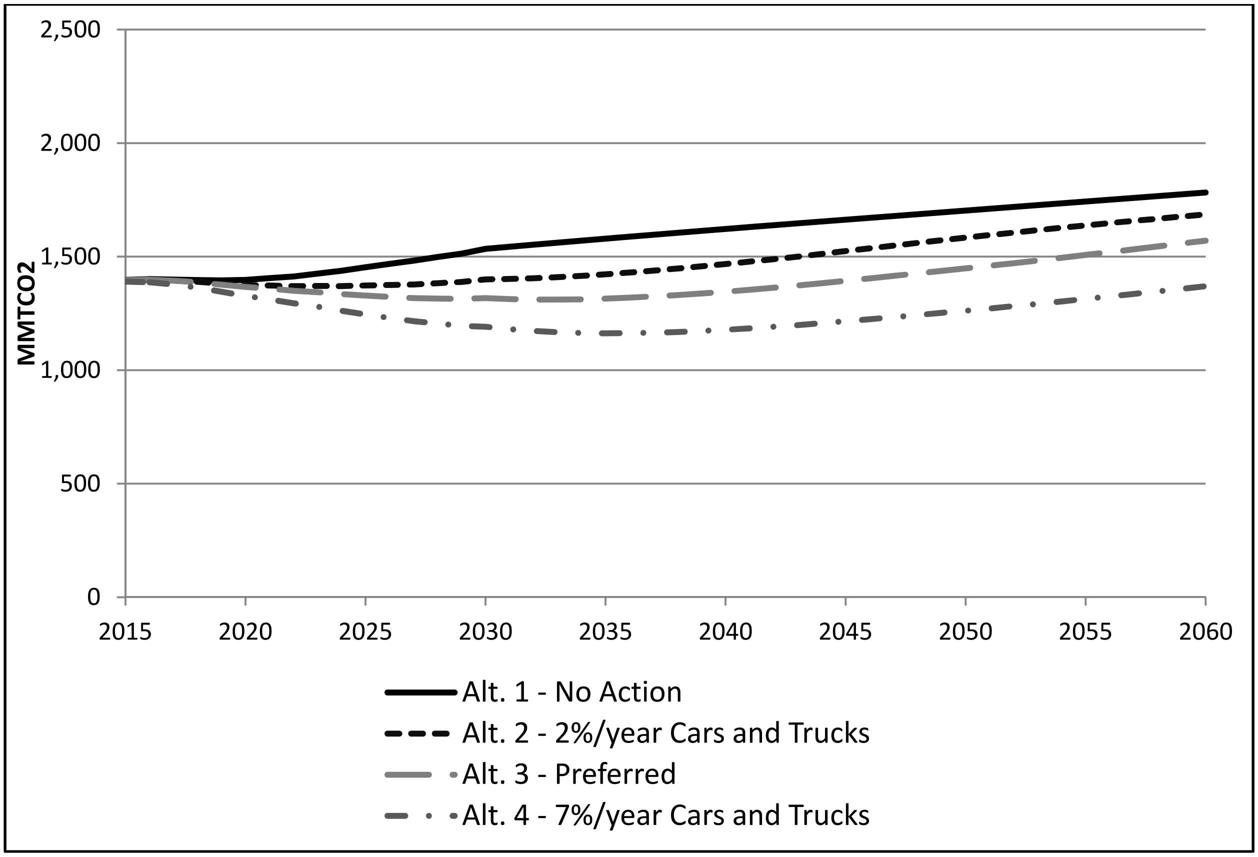


Table 5.4.1-2-A. Emissions of Greenhouse Gases ($MMTCO_2e$ per year)[a] from U.S. Passenger Cars and Light Trucks by Alternative, Analysis A

Greenhouse Gas and Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/Year Cars and Trucks	Preferred	7%/Year Cars and Trucks
Carbon dioxide (CO_2)				
2020	1,402	1,378	1,370	1,331
2040	1,761	1,545	1,397	1,227
2060	2,289	2,001	1,801	1,576
2080	2,272	1,987	1,788	1,565
2100	2,114	1,848	1,663	1,455
Methane (CH_4)				
2020	5.18	5.11	5.09	5.01
2040	6.90	6.34	6.17	5.78
2060	8.99	8.25	8.05	7.57
2080	8.93	8.19	8.00	7.51
2100	8.30	7.62	7.44	6.99
Nitrous oxide (N_2O)				
2020	7.23	7.23	7.23	7.16
2040	8.07	8.08	7.73	6.71
2060	10.54	10.58	10.10	8.69
2080	10.47	10.51	10.03	8.63
2100	9.73	9.77	9.33	8.02

a. $MMTCO_2e$ = million metric tons carbon dioxide equivalent.

Table 5.4.1-2-B. Emissions of Greenhouse Gases ($MMTCO_2e$ per year)[a] from U.S. Passenger Cars and Light Trucks by Alternative, Analysis B

Greenhouse Gas and Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	No Action	2%/Year Cars and Trucks	Preferred	7%/Year Cars and Trucks
Carbon dioxide (CO_2)				
2020	1,398	1,375	1,366	1,327
2040	1,622	1,467	1,346	1,178
2060	1,783	1,686	1,571	1,369
2080	1,770	1,674	1,560	1,360
2100	1,646	1,557	1,451	1,265
Methane (CH_4)				
2020	5.17	5.10	5.08	5.00
2040	6.50	6.11	6.08	5.88
2060	7.54	7.34	7.50	7.38
2080	7.49	7.29	7.45	7.33
2100	6.96	6.78	6.93	6.82

Table 5.4.1-2-B. Emissions of Greenhouse Gases ($MMTCO_2e$ per year)[a] from U.S. Passenger Cars and Light Trucks by Alternative, Analysis B (continued)

Greenhouse Gas and Year	Alternative 1 No Action	Alternative 2 2%/Year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/Year Cars and Trucks
Nitrous oxide (N_2O)				
2020	7.23	7.23	7.23	7.16
2040	8.11	8.11	7.72	6.52
2060	10.76	10.72	10.15	8.46
2080	10.68	10.64	10.08	8.40
2100	9.93	9.90	9.37	7.81

a. $MMTCO_2e$ = million metric tons carbon dioxide equivalent.

The preceding tables also illustrate that, in either analysis, each action alternative would reduce passenger car and light truck emissions of CO_2 from their projected levels under the No Action Alternative. Similarly, under each of the action alternatives, CH_4 and N_2O emissions in future years are projected to decline from their projected levels under the No Action Alternative. Progressively larger reductions in CO_2, CH_4, and N_2O emissions from their levels under the No Action Alternative are projected to occur across Alternatives 2 through 4, because these action alternatives require progressively larger increases in fuel economy.

These results can be viewed in light of GHG emissions reduction targets. In 2010, President Obama submitted to the UNFCCC a GHG emissions reduction target for the United States in the range of 17 percent below 2005 levels by 2020, in association with the Copenhagen Accord.[47] Although the action alternatives would reduce projected CO_2 emissions in 2020 compared to what they would otherwise be without action, total CO_2 emissions from the U.S. passenger car and light truck sector in 2020 would decrease in the range of 6.7 to 9.9 percent below 2005 levels in Analysis A and 6.9 to 10.2 percent below 2005 levels in Analysis B,[48] in part because of projected increases in total VMT by passenger cars and light trucks in the future. Figure 5.4.1-3-A and Figure 5.4.1-3-B show that NHTSA estimates the proposed standards would reduce CO_2 emissions significantly from future levels that would otherwise be estimated to occur in the absence of the proposed fuel economy standards. However, these reductions in emissions are not sufficient by themselves to reduce total passenger car and light truck emissions to the goal of 17 percent below their 2005 levels by 2020.

The President's target outlined above does not specify that every emitting sector of the economy must contribute equally proportional emission reductions. Significantly, the action of setting fuel economy standards does not directly regulate total emissions from passenger cars and light trucks. NHTSA's authority to promulgate new fuel economy standards does not allow the agency to regulate other factors affecting emissions, including driving habits; therefore, NHTSA cannot control VMT. Under all of the alternatives, growth in the number of passenger cars and light trucks in use throughout the United States combined with assumed increases in

[47] On January 28, 2010, the United States submitted this target to the UNFCCC as part of a January 31 deadline negotiated in Copenhagen in December 2009, "in conformity with anticipated U.S. energy and climate legislation, recognizing that the final target will be reported to the [U.N.] in light of enacted legislation" (U.S. Department of State 2010).

[48] A 17 percent reduction would mean a reduction of 251.1 $MMTCO_2$ from 2005 levels, or a reduction of 176.1 $MMTCO_2$ from the no action alternative.

their average use (annual VMT per vehicle), due to economic improvement and a variety of other factors, is projected to result in growth in light-duty vehicle VMT.

Figure 5.4.1-3-A. Projected Annual CO_2 Emissions from U.S. Passenger Cars and Light Trucks by Alternative Compared to 17% below 2005 Levels, Analysis A

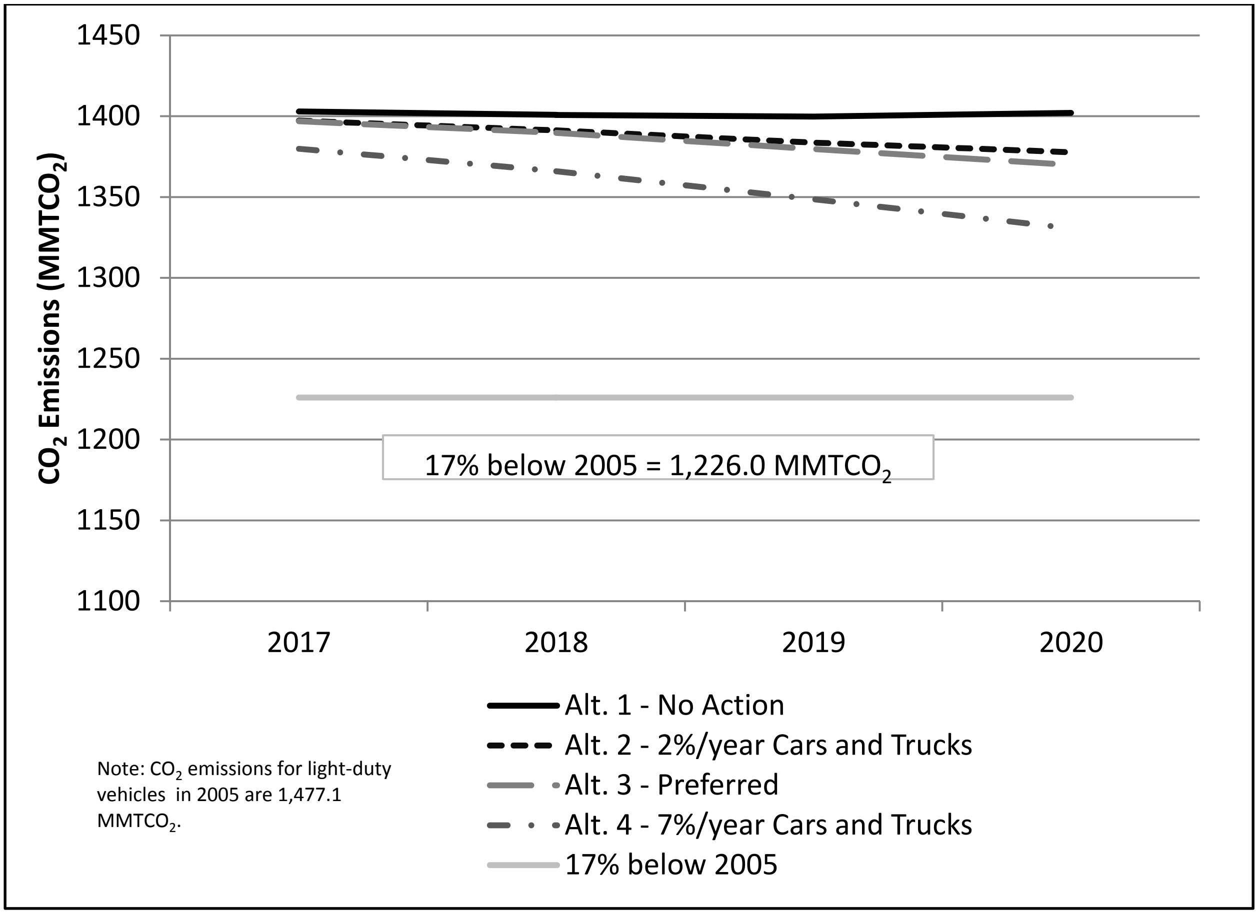
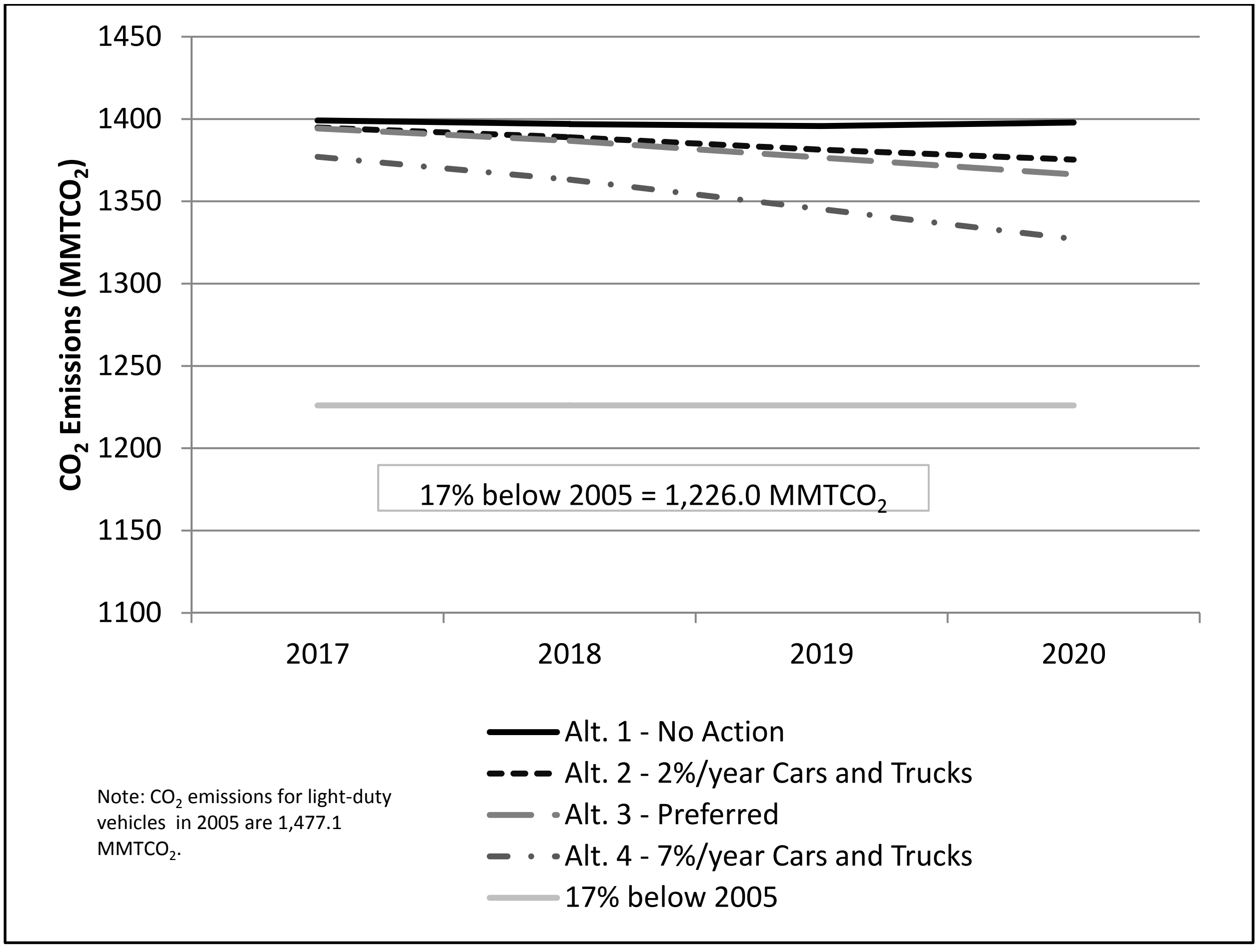


Figure 5.4.1-3-B. Projected Annual CO_2 Emissions from U.S. Passenger Cars and Light Trucks by Alternative Compared to 17% below 2005 Levels, Analysis B



This projected growth in travel is expected to more than offset the effect of improvements in fuel economy for all alternatives (except for Alternative 4 in Analysis B), resulting in increases in total fuel consumption by passenger cars and light trucks in the United States by 2060 and over the long term. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from passenger cars and light trucks. However, NHTSA anticipates reduced annual fuel consumption and CO_2 emissions from present levels in the short term under these alternatives. Under Alternative 4 in Analysis B, increases in fuel economy are expected to result in fuel consumption and CO_2 emission levels through and beyond 2060 that are lower than present annual CO_2 emission levels.

As an illustration of the fuel savings projected to result from this action, Figure 5.4.1-4-A expresses the CO_2 reductions from each action alternative in 2025 as the equivalent number of passenger cars and light trucks that would produce those emissions in that year in Analysis A. The emission reductions from the action alternatives are equivalent to the annual emissions of between 13.2 million light-duty vehicles (Alternative 2) and 32.9 million light-duty vehicles (Alternative 4) in 2025, compared to the annual emissions that would occur under the No Action Alternative. Emission reductions in 2025 under the Preferred Alternative are equivalent to the annual emissions of 20.2 million passenger cars and light trucks. These annual CO_2 reductions, their equivalent in vehicles, and differences among alternatives grow larger in future years as older vehicles continue to be replaced by newer ones meeting the increasingly stringent fuel economy standards required under each alternative.[49]

Figure 5.4.1-4-A. Number of U.S. Passenger Cars and Light Trucks Equivalent to CO_2 Reductions in 2025 Compared to the No Action Alternative, Analysis A

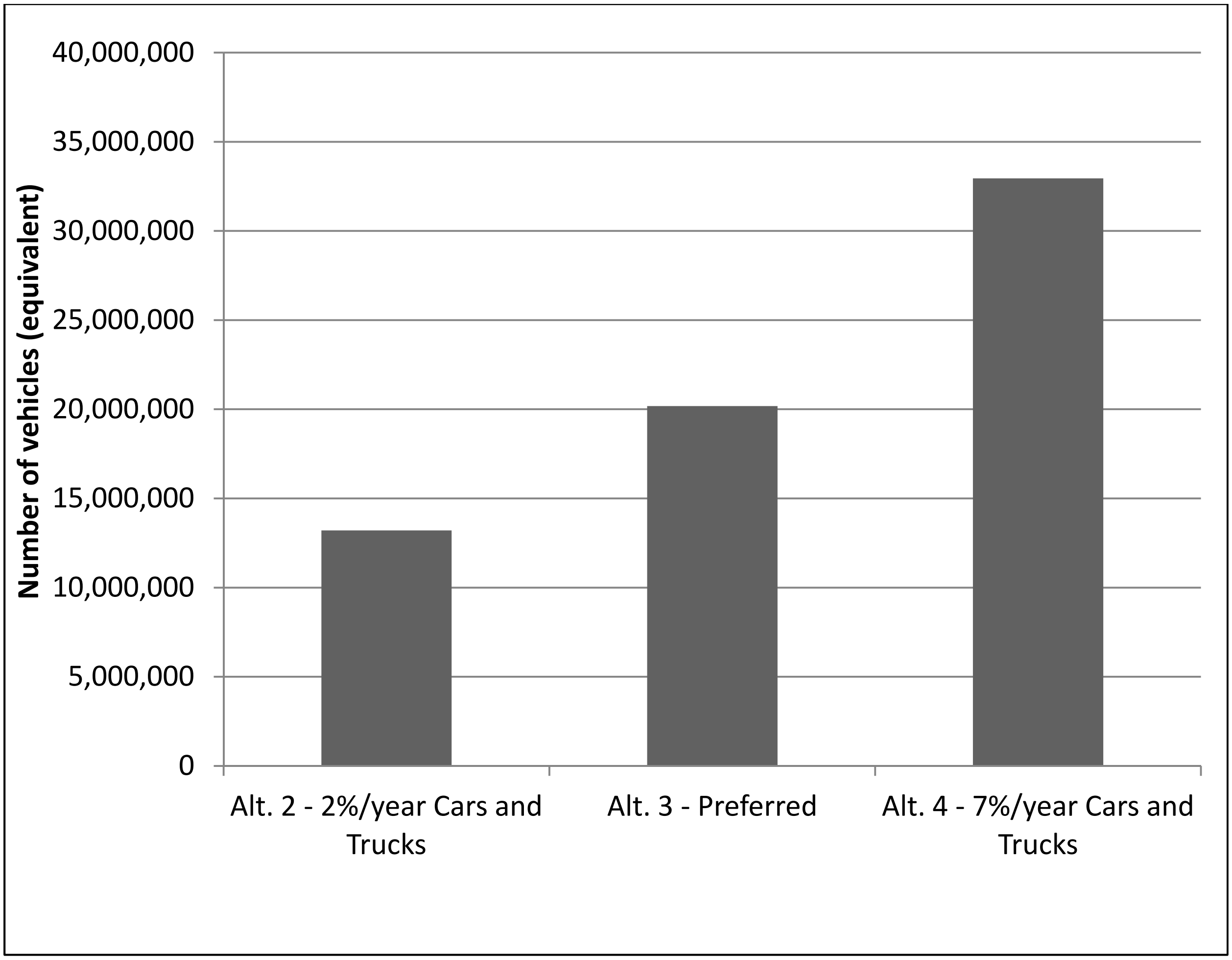
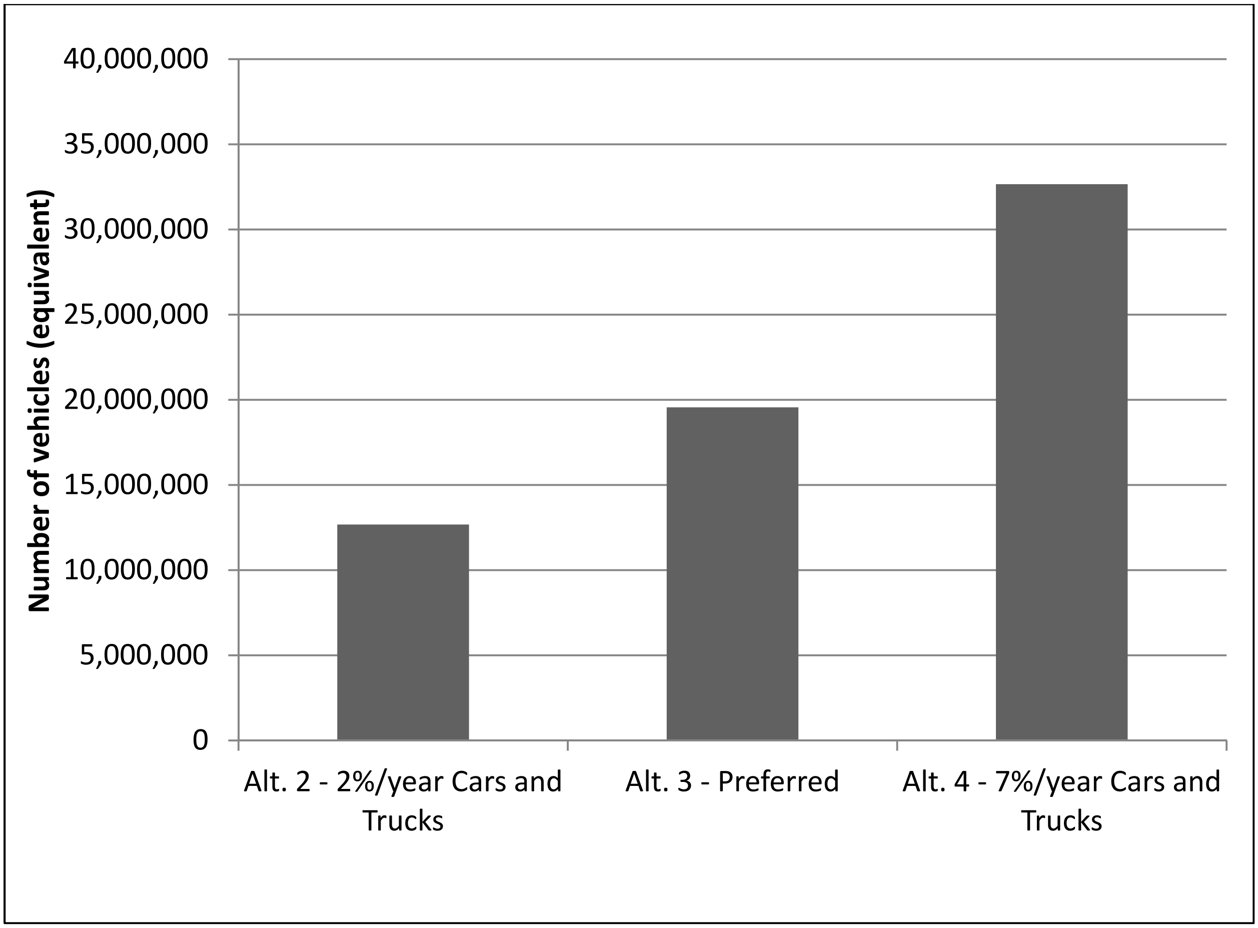


Figure 5.4.1-4-B expresses the CO_2 reductions projected to result from each action alternative in 2025 as the equivalent number of passenger cars and light trucks that would produce those emissions in that year in Analysis B. The emission reductions from the action alternatives are equivalent to the annual emissions of between 12.7 million light-duty vehicles (Alternative 2) and 32.7 million light-duty vehicles (Alternative 4) in 2025, compared to the annual emissions that would occur under the No Action Alternative. Emission reductions in 2025 under the Preferred Alternative are equivalent to the annual emissions of 19.6 million light-duty vehicles. These annual CO_2 reductions, their equivalent in vehicles, and differences among alternatives grow

[49] The light-duty vehicle equivalency is based on an average per-vehicle emissions estimate, which includes both tailpipe CO_2 emissions and associated upstream emissions from fuel production and distribution. The average light-duty vehicle accounts for approximately 6.40 metric tons of CO_2 in 2025 in Analysis A based on Volpe and GREET model analysis.

larger in future years as older vehicles continue to be replaced by newer ones meeting the increasingly stringent fuel economy standards required under each alternative.[50]

Figure 5.4.1-4-B. Number of U.S. Passenger Cars and Light Trucks Equivalent to CO_2 Reductions in 2025 Compared to the No Action Alternative, Analysis B



These emission reductions can also be compared to existing programs designed to reduce GHG emissions in the United States. In 2007, Arizona, California, New Mexico, Oregon, and Washington formed the WCI to develop regional strategies to address climate change and stated a goal of reducing 350 $MMTCO_2e$ over the period 2009 to 2020 (WCI 2007).[51] As of 2011, seven U.S. states and four Canadian provinces have partnered under the WCI to collaboratively reduce their GHG emissions. In 2010, WCI released its “Design for the Regional WCI Program,” in which WCI explains its commitment to, and strategy for, reducing GHG emissions within the WCI region by 15 percent below 2005 levels by 2020 (WCI 2010). Ten northeastern and mid-Atlantic States have formed the RGGI to reduce CO_2 emissions from power plants in the Northeast by 10 percent by 2018 (RGGI 2011). Projected emission

[50] The light-duty vehicle equivalency is based on an average per-vehicle emissions estimate, which includes both tailpipe CO_2 emissions and associated upstream emissions from fuel production and distribution. The average light-duty vehicle accounts for approximately 6.38 metric tons of CO_2 in 2025 in Analysis B based on Volpe and GREET model analysis.

[51] Since this goal was initially stated, Montana, Quebec, Ontario, British Columbia, Manitoba, and Utah have joined the WCI. Therefore, the total emissions reduction would likely be much greater than 350 $MMTCO_2$.

reductions from 2006 to 2024 under the initiative were estimated at 268 $MMTCO_2$ when this program began in 2006 (RGGI 2006).[52] This estimate represents a 23 percent reduction in relation to the future baseline (as estimated in 2006) and a 10 percent reduction in 2024 emissions from their levels at the beginning of the action (RGGI 2006). By comparison, the proposed MY 2017–2025 CAFE standards are projected to reduce CO_2 emissions by 349 to 927 $MMTCO_2$ in Analysis A and 326 to 918 $MMTCO_2$ in Analysis B between 2017 and 2025 (depending on the alternative), with emissions levels representing a 6 to 17 percent reduction from the baseline emissions for U.S. passenger cars and light trucks in 2025 (in both Analyses A and B).

Two features of these comparisons are important to emphasize. First, emissions from the sources addressed in the WCI and RGGI plans are projected to decrease compared to the beginning of the action (conforming to the programs' goals, which are to reduce overall emissions), while total emissions from the vehicles covered under the proposed rule are projected to *increase* in the long term under most alternatives due to increases in vehicle ownership and use. Second, these projections are estimates only, and the scope of these climate programs differs from the scope of the proposed standards in terms of geography, sector, and purpose.

In this case, the comparison of emission reductions from the alternative fuel economy standards to emission reductions associated with other programs is intended to benefit decisionmakers by providing relative benchmarks, rather than absolute metrics, for selecting among alternatives. In summary, the alternatives analyzed in this EIS deliver GHG emission reductions that are on a scale similar to many of the most progressive and ambitious GHG emissions reduction programs underway in the United States.

5.4.1.2 Social Cost of Carbon

Tables 5.4.1-3-A and 5.4.1-3-B provide the benefits of the proposed CAFE standards in terms of reduced monetized damages. NHTSA derived the net present value of the benefits reported in Tables 5.4.1-3-A and 5.4.1-3-B by (1) utilizing the estimates of the SCC (per ton) reported previously in Section 5.3.2; (2) applying each future year's SCC estimate (per ton) to the projected reduction in CO_2 emissions during that year under each Action Alternative, presented in Section 5.4.1; (3) discounting the resulting figure to its present value; and (4) summing those estimates for each year from 2017 to 2050. For internal consistency, the annual benefits are discounted to net present value terms using the same discount rate as each SCC estimate (i.e., 5 percent, 3 percent, and 2.5 percent), rather than the 3 percent and 7 percent discount rates applied to other future benefits. These estimates show increasing benefits with decreasing discount rates and with higher CO_2 damage estimates. The estimated net present value for a given action alternative varies by approximately an order of magnitude across the discount rates. The estimated net present value computed using a single discount rate differs by roughly a factor of three across alternatives.

[52] Emission reductions were estimated by determining the difference between the RGGI Cap and the Phase III RGGI reference case. These estimates do not include offsets. Offsets are credits created by projects outside the cap system that decrease or sequester emissions in a way that is additional, verifiable, and permanent. Capped/ regulated entities can use these offsets for compliance, thus allowing regulated entities to emit more, but allow reductions elsewhere.

Table 5.4.1-3-A. Reduced Monetized Damages of Climate Change for each Regulatory Alternative Net Present Value in 2011 of CO_2 Emission Reductions between 2017 and 2050 (in millions of 2009 dollars), Analysis A

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
2 - 2%/year Cars and Trucks	$16,428	$88,337	$151,186	$268,878
3 - Preferred	$27,013	$145,638	$249,391	$443,247
4 - 7%/year Cars and Trucks	$40,888	$219,669	$375,893	$668,653

Table 5.4.1-3-B. Reduced Monetized Damages of Climate Change for each Regulatory Alternative Net Present Value in 2011 of CO_2 Emission Reductions between 2017 and 2050 (in millions of 2009 dollars), Analysis B

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
2 - 2%/year Cars and Trucks	$12,385	$65,521	$111,761	$199,536
3 - Preferred	$21,394	$114,040	$194,827	$347,207
4 - 7%/year Cars and Trucks	$35,171	$187,398	$320,125	$570,577

5.4.1.3 Direct and Indirect Impacts on Climate Change Indicators

Sections 5.4.1.3.1 through 5.4.1.3.4 describe the direct and indirect impacts of the alternatives on four relevant climate change indicators: atmospheric CO_2 concentrations, temperature, precipitation, and sea-level rise. Section 5.4.2.3.5 presents the sensitivity analysis.

5.4.1.3.1 Atmospheric CO_2 Concentrations

MAGICC 5.3.v2 is a simple climate model that is well calibrated to the mean of the multi-model ensemble results for three of the most commonly used emissions scenarios – B1 (low), A1B (medium), and A2 (high) from the IPCC SRES series – as shown in Table 5.4.1-4.[53] As the table indicates, the results of the model runs developed for this analysis agree relatively well with IPCC estimates for both CO_2 concentrations and surface temperature.

Table 5.4.1-4. Comparison of MAGICC Modeling Results and Reported IPCC Results[a,b]

Scenario	CO_2 Concentration (ppm)		Global Mean Increase in Surface Temperature (°C)		Sea-Level Rise (cm)	
	IPCC WGI (2100)	MAGICC (2100)	IPCC WGI (2080–2099)	MAGICC (2090)	IPCC WGI (2090–2099)	MAGICC (2095)
B1 (low)	550	538.3	1.79	1.81	28	26
A1B (medium)	715	717.2	2.65	2.76	35	35
A2 (high)	836	866.8	3.13	3.31	37	38

a. IPCC 2007a.
b. The IPCC values represent the average of the 5 to 95 percent range of the rise of sea level from 1980 through 1989 and 2090 through 2099.

[53] NHTSA used the default climate sensitivity in MAGICC of 3.0 °C (5.4 °F).

A comparison of sea-level rise from MAGICC 5.3.v2 and the IPCC Fourth Assessment Report is presented in the release documentation for MAGICC 5.3.v2 (Wigley 2008). In Table 3 of the documentation, Wigley presents the results for six SRES scenarios, which show that the comparable values for sea-level rise from MAGICC 5.3.v2 (total sea-level rise minus estimates for contributions from non-melt sources such as warming of the permafrost) are within 0.01 centimeter in 2095.

As discussed in Section 5.3.3, NHTSA used the GCAMReference scenario to represent the No Action Alternative in the MAGICC modeling runs. Table 5.4.1-5-A and Table 5.4.1-5-B, in addition to Figures 5.4.1-5-A and B through 5.4.1-8-A and B, present the results of MAGICC simulations for the No Action Alternative and the three action alternatives in terms of CO_2 concentrations and increases in global mean surface temperature in 2040, 2060, and 2100.

Estimated CO_2 concentrations for 2100 range from 780.3 ppm under Alternative 4 to 784.9 ppm under the No Action Alternative in Analysis A. For Analysis B, CO_2 concentrations range from 781.9 ppm under Alternative 4 to 784.9 ppm under the No Action Alternative in 2100. For 2040 and 2060, the corresponding range is even tighter. Because CO_2 concentrations are the key determinant of other climate effects (which in turn act as drivers on the resource impacts discussed in Section 5.5), this leads to small differences in these effects. Even though these effects are small, they occur on a global scale and are long-lived.

As Figure 5.4.1-6-A and Figure 5.4.1-6-B show, the reduction in the increases in projected CO_2 concentrations under each action alternative compared to the No Action Alternative amounts to a small fraction of the projected total increases in CO_2 concentrations. However, the relative impact of the action alternatives is demonstrated by the reduction in increases of CO_2 concentrations under the range of action alternatives. As shown in Figures 5.4.1-6-A and 5.4.1-6-B, the reduction in the level of increase in CO_2 concentrations by 2100 under Alternative 4 is more than twice that of Alternative 2 in Analysis A and more than three times that of Alternative 2 in Analysis B.

Table 5.4.1-5-A. CO_2 Concentrations, Global Mean Surface Temperature Increase, and Sea-level Rise Using MAGICC (GCAMReference) by Alternative,[a,b] Analysis A

Totals by Alternative	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-Level Rise (cm)[c]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100
1 - No Action	478.8	563.7	784.9	1.191	1.833	3.064	11.21	18.79	37.40
2 - 2%/year Cars and Trucks	478.5	563.0	783.0	1.190	1.830	3.058	11.21	18.78	37.34
3 - Preferred	478.3	562.5	781.8	1.189	1.828	3.053	11.2	18.76	37.30
4 - 7%/year Cars and Trucks	478.1	561.8	780.3	1.188	1.825	3.048	11.2	18.75	37.25
Reductions under Alternative Vehicle Standards									
2 - 2%/year Cars and Trucks	0.3	0.8	1.8	0.001	0.003	0.006	0.00	0.01	0.06
3 - Preferred	0.5	1.3	3.1	0.002	0.005	0.011	0.01	0.03	0.10
4 - 7%/year Cars and Trucks	0.7	1.9	4.5	0.003	0.008	0.016	0.01	0.04	0.15

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.
b. The effects on climate change indicators shown in this table incorporate emission reductions that occur before 2017 due to early compliance with the rulemaking.
c. The values for global mean surface temperature and sea-level rise relate to the year 1990.

Table 5.4.1-5-B. CO_2 Concentrations, Global Mean Surface Temperature Increase, and Sea-level Rise Using MAGICC (GCAMReference) by Alternative,[a,b] Analysis B

Totals by Alternative	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-Level Rise (cm)[c]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100
1 - No Action	478.8	563.7	784.9	1.191	1.833	3.064	11.21	18.79	37.40
2 - 2%/year Cars and Trucks	478.6	563.3	784.1	1.190	1.831	3.061	11.21	18.78	37.37
3 - Preferred	478.4	562.9	783.3	1.189	1.829	3.058	11.20	18.77	37.34
4 - 7%/year Cars and Trucks	478.1	562.3	781.9	1.188	1.827	3.053	11.20	18.76	37.29
Reductions under Alternative Vehicle Standards									
2 - 2%/year Cars and Trucks	0.2	0.4	0.8	0.001	0.002	0.003	0.00	0.01	0.03
3 - Preferred	0.4	0.8	1.6	0.002	0.004	0.006	0.01	0.02	0.06
4 - 7%/year Cars and Trucks	0.7	1.4	3.0	0.003	0.006	0.011	0.01	0.03	0.11

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.
b. The effects on climate change indicators shown in this table incorporate emission reductions that occur before 2017 due to early compliance with the rulemaking.
c. The values for global mean surface temperature and sea-level rise relate to 1990.

Figure 5.4.1-5-A. CO_2 Concentrations (ppm), Analysis A

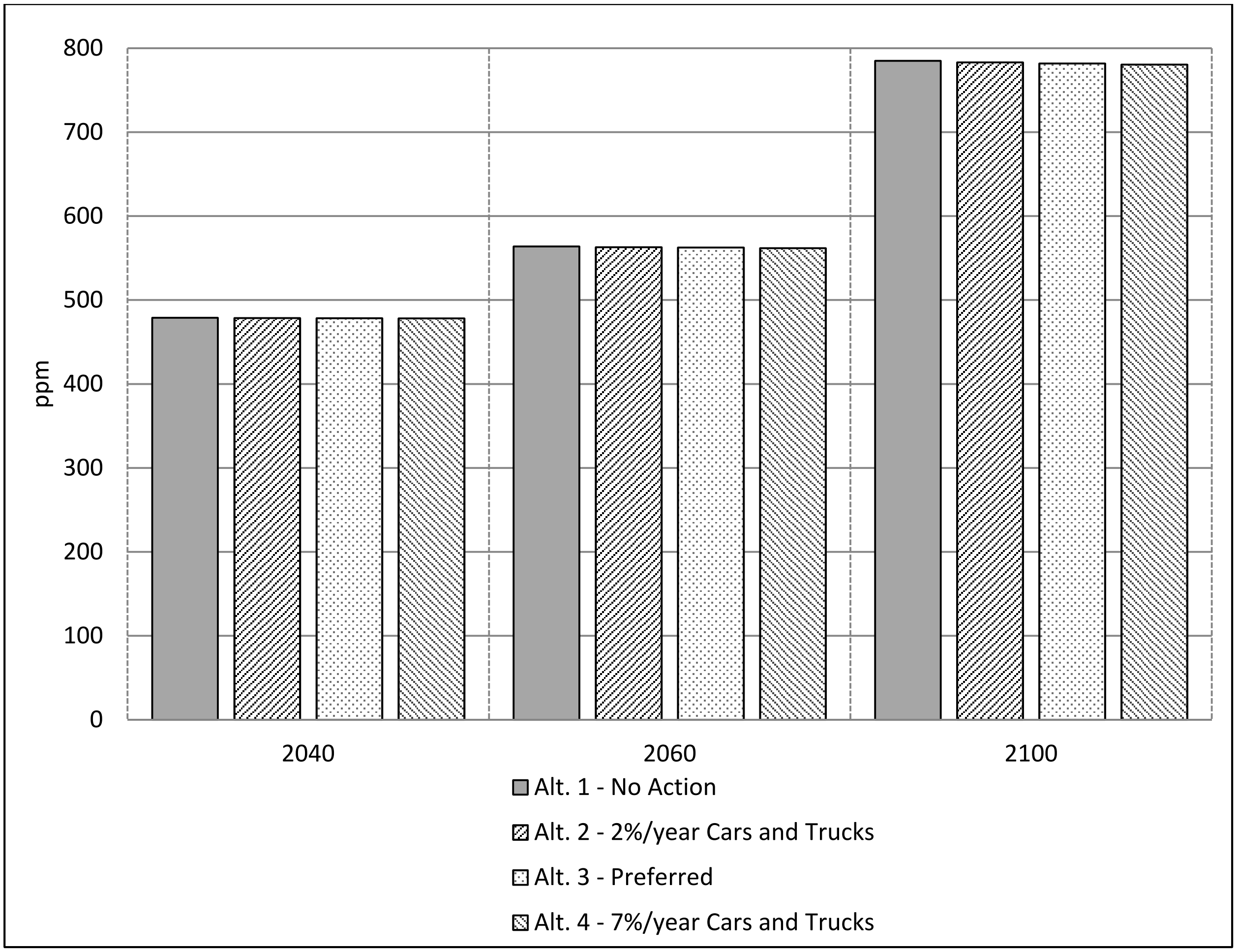


Figure 5.4.1-5-B. CO_2 Concentrations (ppm), Analysis B

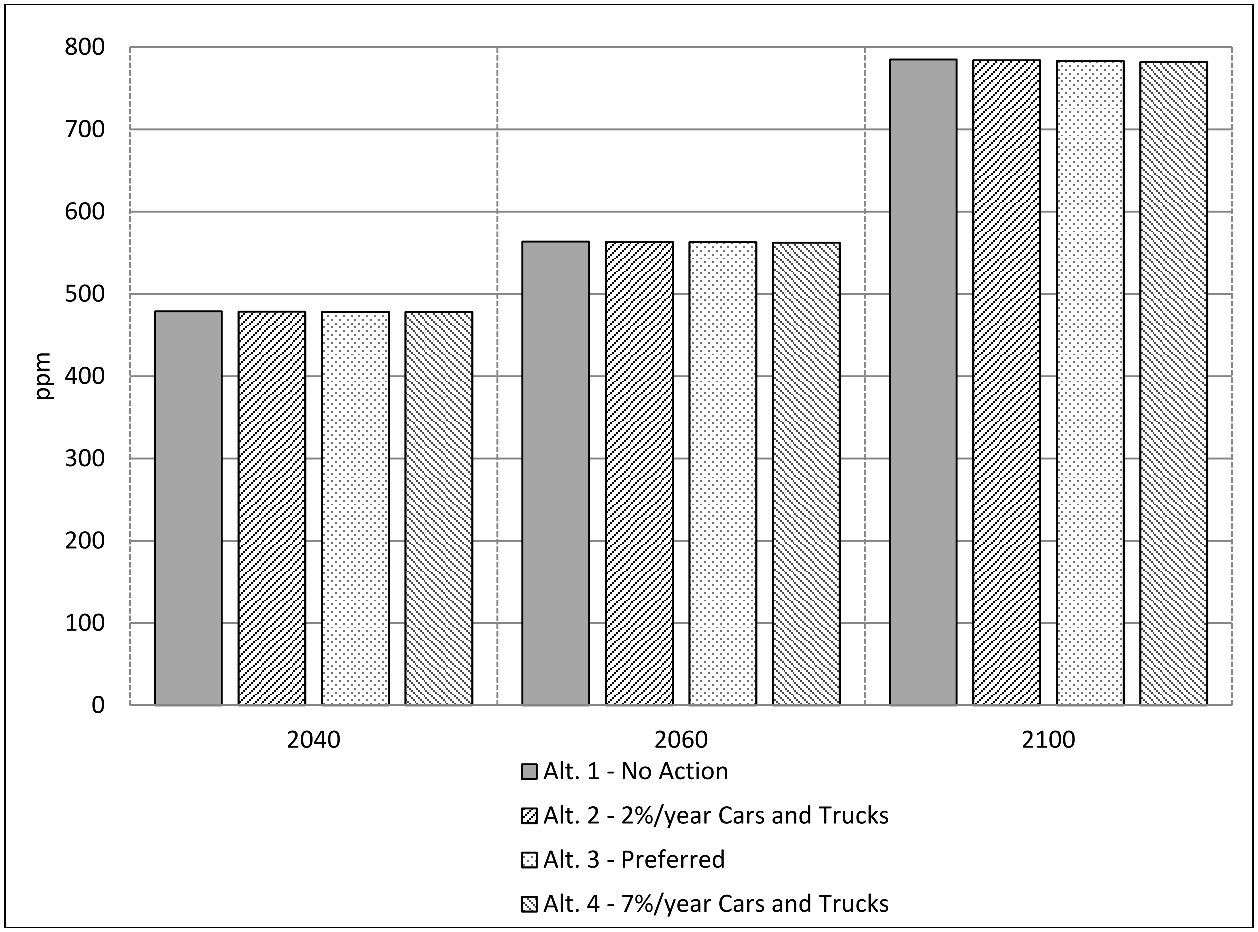


Figure 5.4.1-6-A. Reduction in CO_2 Concentrations (ppm) Compared to the No Action Alternative, Analysis A

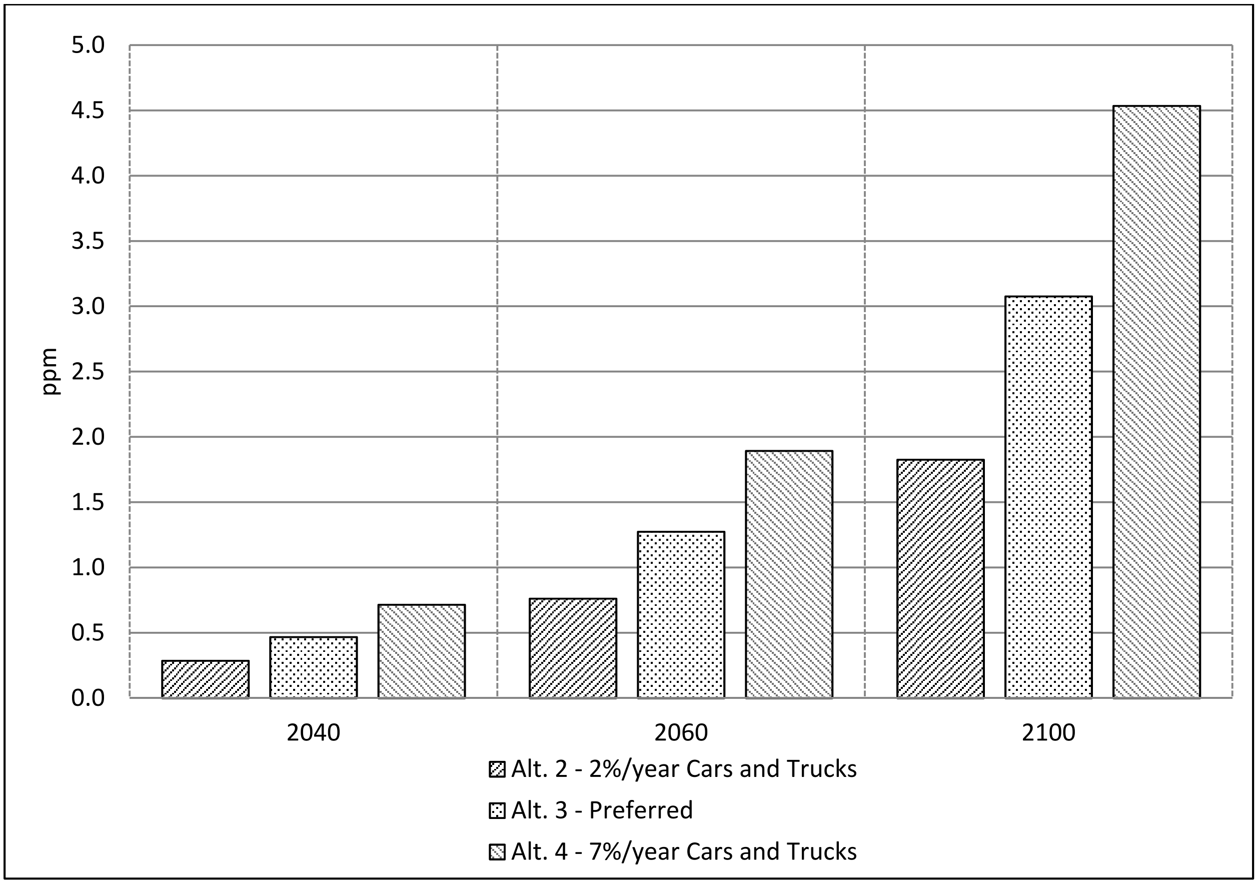
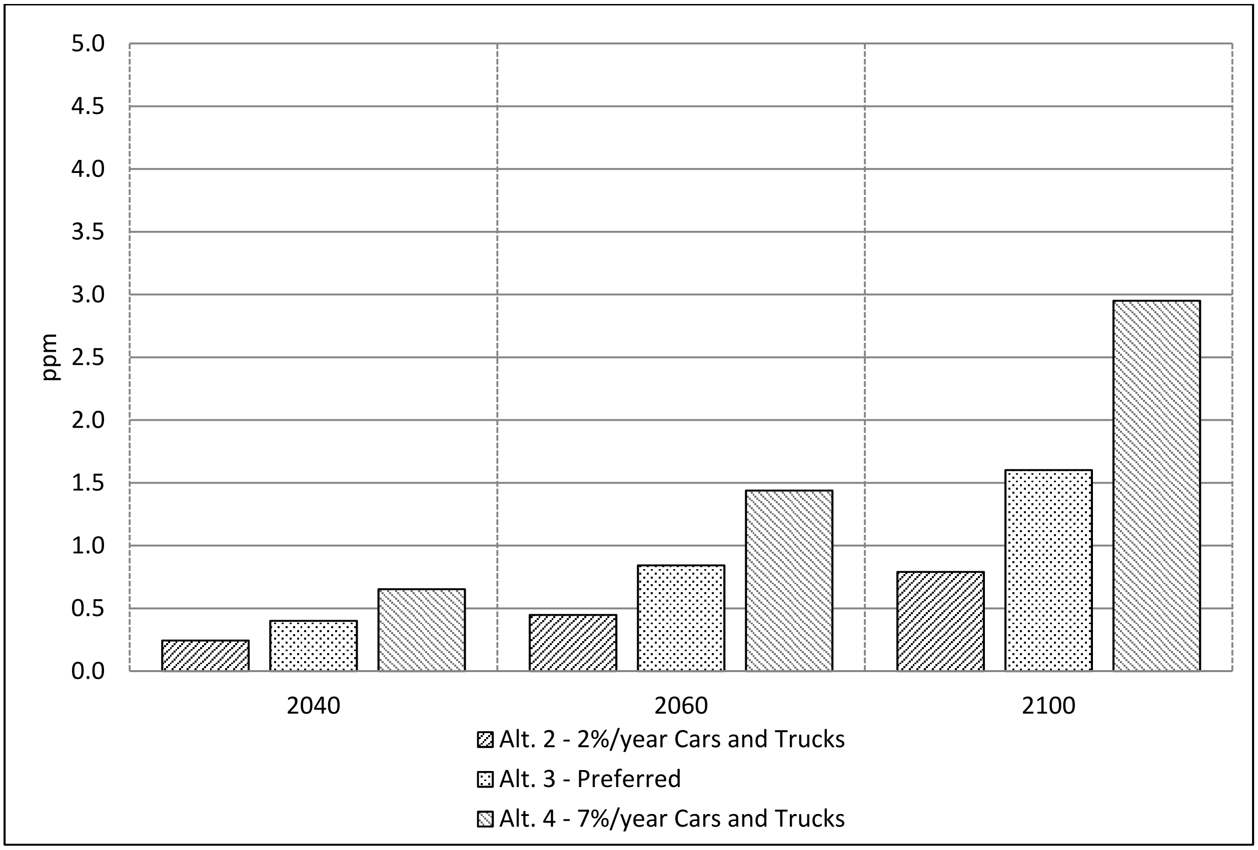


Figure 5.4.1-6-B. Reduction in CO_2 Concentrations (ppm) Compared to the No Action Alternative, Analysis B



5.4.1.3.2 Temperature

Tables 5.4.1-5-A and 5.4.1-5-B list MAGICC simulations of mean global surface air temperature increases. Under the No Action Alternative in both Analysis A and Analysis B,[54] global surface air temperature is projected to increase from 1990 levels by 1.19 °C (2.14 °F) by 2040, 1.83 °C (3.29 °F) by 2060, and 3.06 °C (5.51 °F) by 2100.[55] The differences among the reductions in baseline temperature increases projected to result from the various action alternatives are small compared to total projected changes. For example, in 2100 the reduction in temperature increase compared to the No Action Alternative ranges from 0.006 °C (0.011 °F) under Alternative 2 to 0.016 °C (0.029 °F) under Alternative 4 in Analysis A and from 0.003 °C (0.005 °F) under Alternative 2 to 0.011 °C (0.020 °F) under Alternative 4 in Analysis B. Figures 5.4.1-8-A and 5.4.1-8-B also illustrate that reductions in the growth of projected global mean surface temperature from each action alternative compared to the No Action Alternative are anticipated to be small compared to total projected changes. However, the *relative* impacts of the action alternatives compared to one another can be seen by comparing the reductions in the increases in global mean surface temperature projected to occur under Alternatives 2 and 4. As shown in Figure 5.4.1-8-A and Figure 5.4.1-8-B, the reduction in the projected growth in global temperature under Alternative 4 is more than twice as large as that under Alternative 2 in Analysis A and more than three times as large as that under Alternative 2 in Analysis B.

[54] As discussed above and in Section 5.3.3, NHTSA used the GCAMReference scenario to represent the No Action Alternative in the MAGICC modeling runs. Therefore, the No Action Alternative in the tables in this section are the same. However, *see* Section 5.3.3.2.1 for a description of how benefits for each action alternative were calculated in this section.

[55] Because the actual increase in global mean surface temperature lags the commitment to warming, the impact on global mean surface temperature increase is less than the impact on the long-term commitment to warming. The actual increase in surface temperature lags the commitment due primarily to the time required to heat the ocean to the level committed by the concentrations of the GHGs.

Figure 5.4.1-7-A. Global Mean Surface Temperature Increase (°C), Analysis A

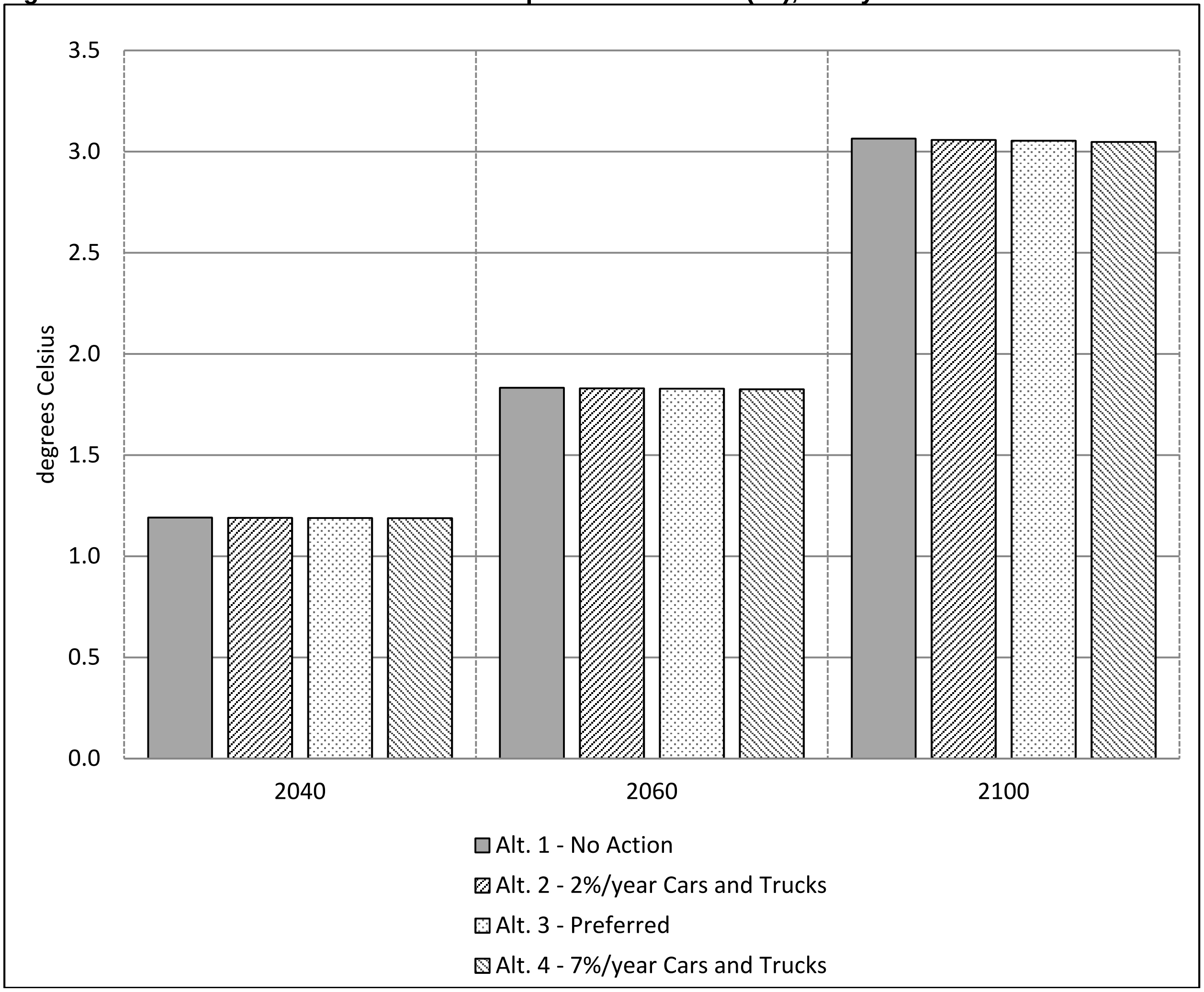


Figure 5.4.1-7-B. Global Mean Surface Temperature Increase (°C), Analysis B

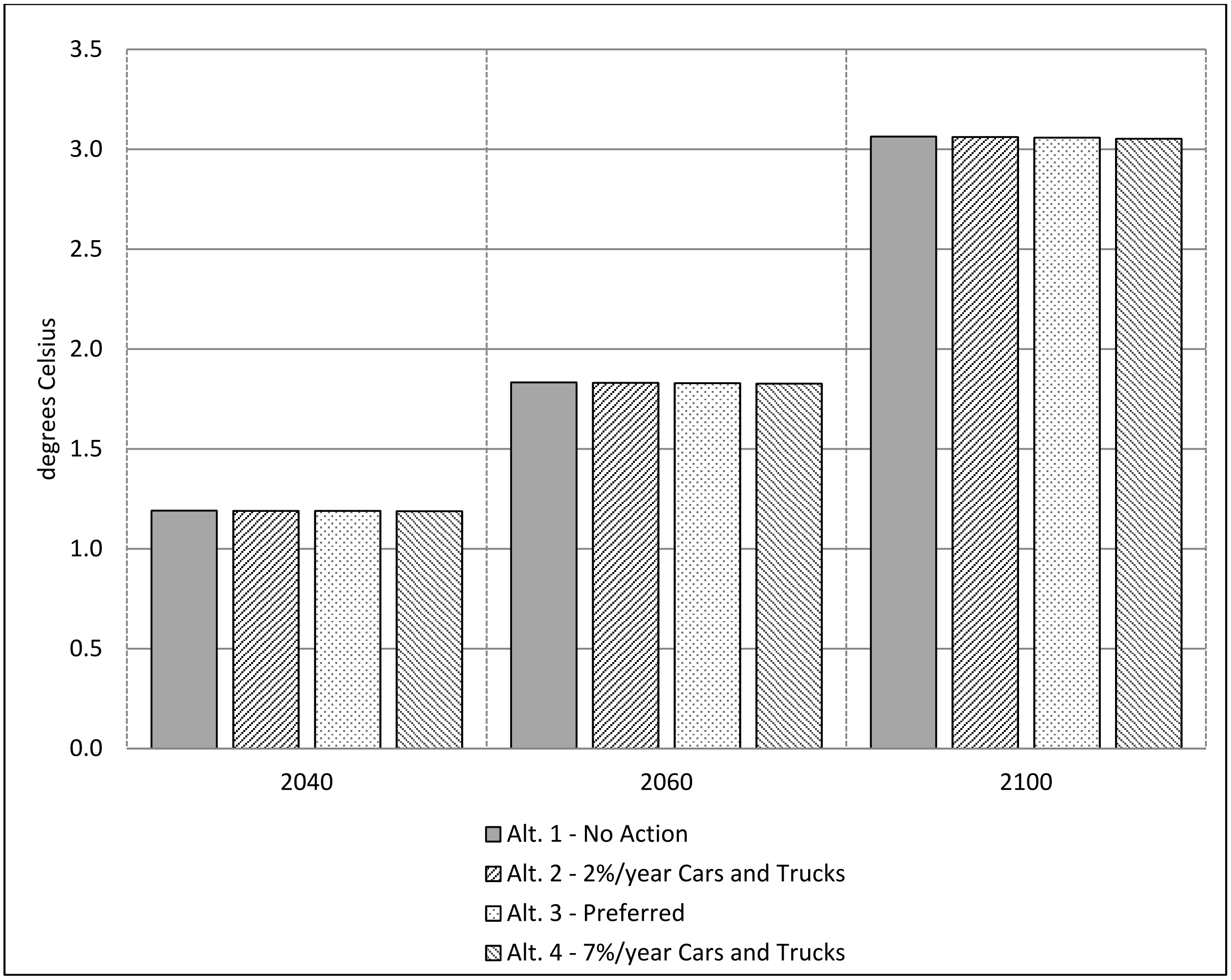


Figure 5.4.1-8-A. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative, Analysis A

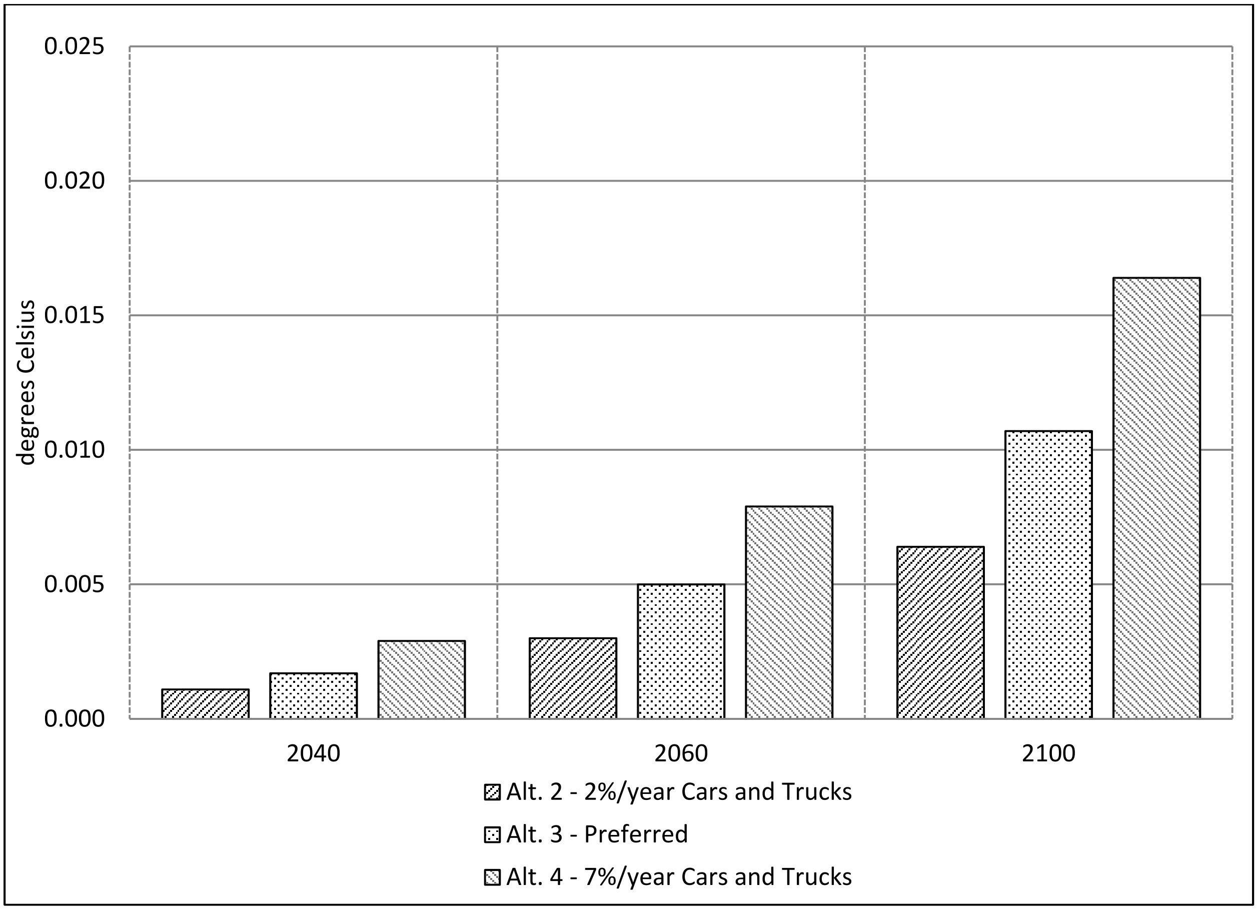


Figure 5.4.1-8-B. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative, Analysis B

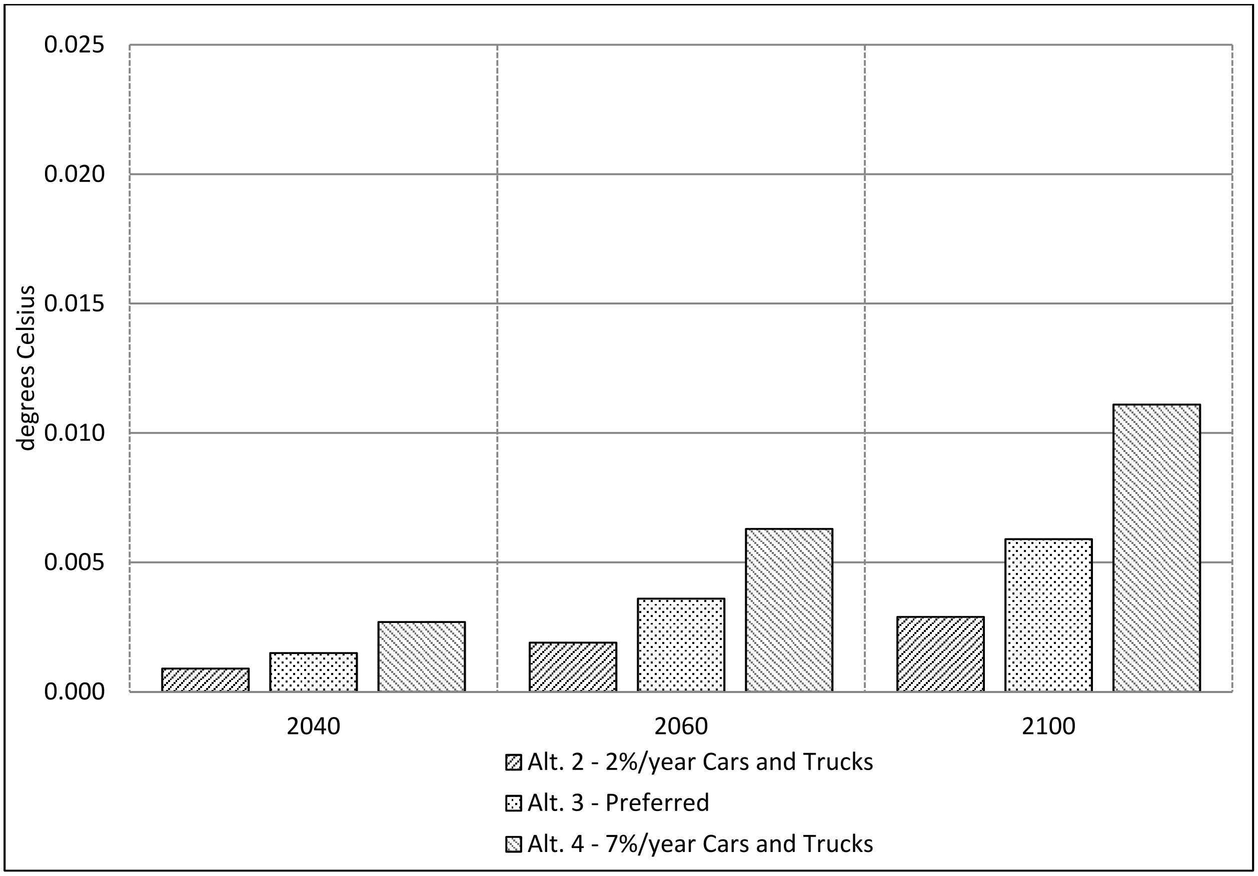


Table 5.4.1-6 summarizes the regional changes in warming and seasonal temperatures presented in the IPCC Fourth Assessment Report. At this time, quantifying the changes in regional climate as a result of the action alternatives is not possible due to the limitations of existing climate models, but the alternatives would be expected to reduce the regional impacts in proportion to reduction in global mean surface temperature.

Table 5.4.1-6. Summary of Regional Changes to Warming and Seasonal Temperatures Extracted from the IPCC Fourth Assessment Report[a]

Land Area	Sub-region	Mean Warming	Maximum Summer Temperatures
Africa	Mediterranean area and northern Sahara	*Likely* larger than global mean throughout continent and in all seasons	
	Southern Africa and western margins	*Likely* larger than global mean throughout continent and in all seasons	
	East Africa	*Likely* larger than global mean throughout continent and in all seasons	
Mediterranean and Europe	Northern Europe	*Likely* to increase more than the global mean with largest warming in winter	
	Southern and Central Europe	*Likely* to increase more than the global mean with largest warming in winter	Maximum summer temperatures *likely* to increase more than the average
	Mediterranean area	*Likely* to increase more than the global mean with largest warming in winter	
Asia	Central Asia	*Likely* to be well above the global mean	
	Tibetan Plateau	*Likely* to be well above the global mean	
	Northern Asia	*Likely* to be well above the global mean	
	Eastern Asia	*Likely* to be above the global mean	*Very likely* that heat waves/hot spells in summer will be longer, more intense, and more frequent *Very likely* fewer very cold days
	South Asia	*Likely* to be above the global mean	*Very likely* fewer very cold days
	Southeast Asia	*Likely* to be similar to the global mean	

Table 5.4.1-6. Summary of Regional Changes to Warming and Seasonal Temperatures Extracted from the IPCC Fourth Assessment Report[a] (continued)

Land Area	Sub-region	Mean Warming	Maximum Summer Temperatures
North America	Northern regions/Northern North America	*Likely* to exceed the global mean warming	Warming is *likely* to be greatest in winter. Minimum winter temperatures are *likely* to increase more than the average
	Southwest		Warming is *likely* to be greatest in summer Maximum summer temperatures are *likely* to increase more than the average
Central and South America	Southern South America	*Likely* to be similar to the global mean warming	
	Central America	*Likely* to be larger than global mean warming	
Australia and New Zealand	Southern Australia	*Likely* comparable to the global mean but less than in the rest of Australia	Increased frequency of extreme high daily temperatures and decreased frequency of cold extremes are *very likely*
	Southwestern Australia	*Likely* comparable to the global mean	
	Rest of Australia	*Likely* comparable to the global mean	
	New Zealand, South Island	*Likely* less than the global mean	
	Rest of New Zealand	*Likely* comparable to the global mean	
Polar Regions	Arctic	*Very likely* to warm during this century more than the global mean	Warming greatest in winter and smallest in summer
	Antarctic	*Likely* to warm	
Small Islands		*Likely* to be smaller than the global annual mean	

a. Christensen et al. 2007.

5.4.1.3.3 Precipitation

In some areas, the increase in energy available to the hydrologic cycle might increase precipitation. Increases in precipitation result from higher temperatures causing greater water evaporation, which causes more water vapor to be available for precipitation (EPA 2009e). Increased evaporation leads to increased precipitation in areas where surface water is sufficient, such as over oceans and lakes. In drier areas, the increased evaporation can actually accelerate surface drying, which can lead to drought conditions (EPA 2009e). Overall, according to IPCC (Meehl et al. 2007), global mean precipitation is expected to increase under all climate scenarios. Spatial and seasonal variations, however, will be considerable.

Generally, precipitation increases are *very likely* to occur in high latitudes, and decreases are *likely* to occur in the sub-tropics (EPA 2009e).

As noted in Section 5.3.3, MAGICC does not directly simulate changes in precipitation, and NHTSA has not undertaken precipitation modeling with a full Atmospheric-Ocean General Circulation Model. However, the IPCC (Meehl et al. 2007) summary of precipitation represents the most thoroughly reviewed, credible means of producing an assessment of this highly uncertain factor. NHTSA expects that the Proposed Action and alternatives would reduce anticipated changes in precipitation (i.e., in a reference case with no GHG emission reduction policies) in proportion to the effects of the alternatives on temperature.

The global mean change in precipitation provided by the IPCC for the A2 (high), A1B (medium), and B1 (low) scenarios (Meehl et al. 2007) is given as the scaled change in precipitation (expressed as a percentage change from 1980 to 1999 averages) divided by the increase in global mean surface warming for the same period (per °C), as shown in Table 5.4.1-7. The IPCC provides scaling factors in the year ranges of 2011 to 2030, 2046 to 2065, 2080 to 2099, and 2180 to 2199. NHTSA used the scaling factors for the GCAMReference scenario in this analysis because MAGICC does not directly estimate changes in global mean precipitation.[56]

Table 5.4.1-7. Global Mean Precipitation Change (scaled, percent per °C)[a]

Scenario	2011–2030	2046–2065	2080–2099	2180–2199
A2 (high)	1.38	1.33	1.45	NA
A1B (medium)	1.45	1.51	1.63	1.68
B1 (low)	1.62	1.65	1.88	1.89

a. Source: Meehl et al. 2007.

Applying these scaling factors to the reductions in global mean surface warming provides estimates of changes in global mean precipitation. The action alternatives are projected to reduce temperature increases and predicted increases in precipitation slightly in relation to the No Action Alternative, as shown in Table 5.4.1-8-A and Table 5.4.1-8-B (based on the A1B [medium] scenario).

[56] Although MAGICC does not estimate changes in precipitation, SCENGEN (Scenario Generator) does. SCENGEN is an added component to MAGICC 5.3v2; it scales regional results of AOGCM models based on global mean surface temperature change and regional aerosol emissions from MAGICC.

Table 5.4.1-8-A. Global Mean Precipitation (percent Increase) Based on GCAMReference Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative,[a] Analysis A

Scenario	2020	2055	2090
Global Mean Precipitation Change (scaling factor, % change in precipitation per °C change in temperature)	1.45	1.51	1.63
Global Temperature Above Average 1980–1999 Levels (°C) for the GCAMReference Scenario by Alternative[b]			
Alternative 1 - No Action	0.600	1.675	2.760
Alternative 2 - 2%/year Cars and Trucks	0.599	1.673	2.755
Alternative 3 - Preferred	0.599	1.671	2.751
Alternative 4 - 7%/year Cars and Trucks	0.599	1.669	2.746
Reduction in Global Temperature (°C) by Alternative, Mid-level Results (Compared to the No Action Alternative)[c]			
Alternative 2 - 2%/year Cars and Trucks	0.000	0.002	0.006
Alternative 3 - Preferred	0.000	0.004	0.010
Alternative 4 - 7%/year Cars and Trucks	0.000	0.007	0.015
Global Mean Precipitation Increase (%)			
Alternative 1 - No Action	0.87%	2.53%	4.50%
Alternative 2 - 2%/year Cars and Trucks	0.87%	2.53%	4.49%
Alternative 3 - Preferred	0.87%	2.52%	4.48%
Alternative 4 - 7%/year Cars and Trucks	0.87%	2.52%	4.48%
Reduction in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alternative 2 - 2%/year Cars and Trucks	0.00%	0.00%	0.01%
Alternative 3 - Preferred	0.00%	0.01%	0.02%
Alternative 4 - 7%/year Cars and Trucks	0.00%	0.01%	0.02%

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

b. These numbers differ slightly from those in Table 5.4.1-8-A, because the increases in temperature in Table 5.4.1-8-A relate to the global mean surface temperature in 1990, and those in this table represent increases in relation to average temperature in the interval 1980 through 1999.

c. Precipitation changes reported as 0.000 are more than zero but less than 0.001.

Table 5.4.1-8-B. Global Mean Precipitation (percent Increase) Based on GCAMReference Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative,[a] Analysis B

Scenario	2020	2055	2090
Global Mean Precipitation Change (scaling factor, % change in precipitation per °C change in temperature)	1.45	1.51	1.63
Global Temperature Above Average 1980–1999 Levels (°C) for the GCAMReference Scenario by Alternative[b]			
Alternative 1 - No Action	0.600	1.675	2.760
Alternative 2 - 2%/year Cars and Trucks	0.599	1.673	2.758
Alternative 3 - Preferred	0.599	1.672	2.755
Alternative 4 - 7%/year Cars and Trucks	0.599	1.670	2.750
Reduction in Global Temperature (°C) by Alternative, Mid-level Results (Compared to the No Action Alternative)[c]			
Alternative 2 - 2%/year Cars and Trucks	0.000	0.002	0.003
Alternative 3 - Preferred	0.000	0.003	0.005
Alternative 4 - 7%/year Cars and Trucks	0.000	0.006	0.010
Global Mean Precipitation Increase (%)			
Alternative 1 - No Action	0.87%	2.53%	4.50%
Alternative 2 - 2%/year Cars and Trucks	0.87%	2.53%	4.49%
Alternative 3 - Preferred	0.87%	2.52%	4.49%
Alternative 4 - 7%/year Cars and Trucks	0.87%	2.52%	4.48%
Reduction in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alternative 2 - 2%/year Cars and Trucks	0.00%	0.00%	0.00%
Alternative 3 - Preferred	0.00%	0.00%	0.01%
Alternative 4 - 7%/year Cars and Trucks	0.00%	0.01%	0.02%

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.
b. These numbers differ slightly from those in Table 5.4.1-8-B, because the increases in temperature in Table 5.4.1-8-B relate to the global mean surface temperature in 1990, and those in this table represent increases in relation to average temperature in the interval 1980 through 1999.
c. Precipitation changes reported as 0.000 are more than zero but less than 0.001.

In addition to changes in mean annual precipitation, climate change is anticipated to affect the intensity of precipitation.[57]

Regional variations and changes in the intensity of precipitation events cannot be quantified further, primarily due to the lack of available AOGCMs required to estimate these changes. These models typically are used to provide results among scenarios with very large changes in emissions, such as the SRES B1 (low), A1B (medium), and A2 (high) scenarios; very small changes in emissions profiles (such as those resulting from the action alternatives considered here) would produce results that would be difficult to resolve among scenarios. Also, the

[57] As described in Meehl et al. 2007, the "intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation. Even in areas where mean precipitation decreases (most subtropical and mid-latitude regions), precipitation intensity is projected to increase but periods between rainfall events would be longer. The mid-continental areas tend to dry during summer, indicating a greater risk of droughts in those regions. Precipitation extremes increase more than the mean in most tropical and mid- and high-latitude areas."

multiple AOGCMs produce results that are regionally consistent in some cases but inconsistent in others.

Table 5.4.1-9 summarizes, in qualitative terms, the regional changes in precipitation from the IPCC Fourth Assessment Report. Quantifying the changes in regional climate from the action alternatives is not possible at this time, but the alternatives would be expected to reduce the relative precipitation changes in proportion to the reduction in global mean surface temperature.

Table 5.4.1-9. Summary of Regional Changes to Precipitation Extracted from the IPCC Fourth Assessment Report[a]

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
Africa	Mediterranean area and northern Sahara	*Very likely* to decrease	
	Southern Africa and western margins	Winter rainfall *likely* to decrease in southern parts	
	East Africa	*Likely* to be an increase in annual mean rainfall	
Mediterranean and Europe	Northern Europe	*Very likely* to increase and extremes are *likely* to increase	*Likely* to decrease.
	Southern and Central Europe		*Likely* to decrease.
	Mediterranean area	*Very likely* to decrease and precipitation days are *very likely* to decrease	*Likely* to decrease.
Asia	Central Asia	Precipitation in summer is *likely* to decrease	
	Tibetan Plateau	Precipitation in boreal winter is *very likely* to increase	
	Northern Asia	Precipitation in boreal winter is *very likely* to increase Precipitation in summer is *likely* to increase	
	Eastern Asia	Precipitation in boreal winter is *likely* to increase Precipitation in summer is *likely* to increase *Very likely* to be an increase in the frequency of intense precipitation Extreme rainfall and winds associated with tropical cyclones are *likely* to increase	
	South Asia	Precipitation in summer is *likely* to increase *Very likely* to be an increase in the frequency of intense precipitation Extreme rainfall and winds associated with tropical cyclones are *likely* to increase	
	Southeast Asia	Precipitation in boreal winter is *likely* to increase in southern parts Precipitation in summer is *likely* to increase in most parts Extreme rainfall and winds associated with tropical cyclones are *likely* to increase	

Table 5.4.1-9. Summary of Regional Changes to Precipitation Extracted from the IPCC Fourth Assessment Report[a] (continued)

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
North America	Northern regions/Northern North America		Snow season length and snow depth are *very likely* to decrease
	Southwest	Annual mean precipitation is *likely* to decrease	Snow season length and snow depth are *very likely* to decrease
	Northeast USA	Annual mean precipitation is *very likely* to increase	Snow season length and snow depth are *very likely* to decrease
	Southern Canada		Snow season length and snow depth are *very likely* to decrease
	Canada	Annual mean precipitation is *very likely* to increase	Snow season length and snow depth are *very likely* to decrease
	Northernmost part of Canada		Snow season length and snow depth are *likely* to increase
Central and South America	Central America	Annual precipitation is *likely* to decrease	
	Southern Andes	Annual precipitation is *likely* to decrease	
	Tierra del Fuego	Winter precipitation is *likely* to increase	
	Southeastern South America	Summer precipitation is *likely* to increase	
	Northern South America	Uncertain how rainfall would change	
Australia and New Zealand	Southern Australia	Precipitation is *likely* to decrease in winter and spring	
	Southwestern Australia	Precipitation is *very likely* to decrease in winter	
	New Zealand, South Island	Precipitation is *likely* to increase in the west	
Polar Regions	Arctic	Annual precipitation is *very likely* to increase. *Very likely* that the relative precipitation increase would be largest in winter and smallest in summer	
	Antarctic	Precipitation *likely* to increase	
Small Islands		Mixed, depending on the region	

a. Christensen et al. 2007

5.4.1.3.4 Sea-level Rise

IPCC identifies four primary components of sea-level rise: (1) thermal expansion of ocean water, (2) melting of glaciers and ice caps, (3) loss of land-based ice in Antarctica, and (4) loss of land-based ice in Greenland (IPCC 2007d). Ice-sheet discharge is an additional factor that could influence sea level over the long term. Ocean circulation, changes in atmospheric pressure, and geological processes can also influence sea-level rise at a regional scale (EPA 2009e). MAGICC calculates the oceanic thermal expansion component of global mean sea-level rise using a nonlinear temperature- and pressure-dependent expansion coefficient (Wigley 2008). It also addresses the other three primary components through ice-melt models for small glaciers and the Greenland and Antarctic ice sheets, and excludes non-melt sources, which the IPCC Fourth Assessment Report also excluded. Neither MAGICC 5.3.v2 nor the IPCC Fourth Assessment Report includes more recent information, suggesting that ice flow from Greenland and Antarctica will be accelerated by projected temperature increases.

The state of science reflected as of the publication of the IPCC Fourth Assessment Report projects a sea-level rise of 18 to 59 centimeters (0.6 to 1.9 feet) by 2090 to 2099 (EPA 2009e). This projection does not include all changes in ice-sheet flow or the potential for rapid acceleration in ice loss (Pew Center on Global Climate Change 2007 citing Alley et al. 2005, Gregory and Huybrechts 2006, and Hansen 2005). Several recent studies have found that the IPCC might have underestimated potential sea-level rise as a result of loss of the Greenland and Antarctic ice sheets (Shepherd and Wingham 2007, Csatho et al. 2008) and ice loss from mountain glaciers (Meier et al. 2007). Further, IPCC results for sea-level projections might underestimate sea-level rise due to changes in global precipitation (Wentz et al. 2007, Zhang et al. 2007). Rahmstorf (2007) used a semi-empirical approach to project future sea-level rise. The approach yielded a proportionality coefficient of 3.4 millimeters per year per degree Celsius of warming, and a projected sea-level rise of 0.5 to 1.4 meters (1.6 to 4.6 feet) above 1990 levels in 2100 when applying IPCC Third Assessment Report warming scenarios. Rahmstorf (2007) concludes that “[a] rise over 1 meter [3.3 feet] by 2100 for strong warming scenarios cannot be ruled out.” None of these studies takes into account the potential complex changes in ocean circulation that might further influence sea-level rise. Section 5.5.4 discusses sea-level rise in more detail.

Tables 5.4.1-5-A and 5.4.1-5-B list the impacts of the action alternatives on sea-level rise under the GCAMReference scenario.

Analysis A shows a sea-level rise in 2100 ranging from 37.40 centimeters (14.72 inches) under the No Action Alternative to 37.25 centimeters (14.67 inches) under Alternative 4. This represents a maximum reduction of 0.15 centimeters (0.06 inches) by 2100 under Alternative 4 compared to the No Action Alternative.

Analysis B shows a sea-level rise in 2100 ranging from 37.40 centimeters (14.72 inches) under the No Action Alternative to 37.29 centimeters (14.68 inches) under Alternative 4. This represents a maximum reduction of 0.11 centimeters (0.04 inches) by 2100 under Alternative 4 compared to the No Action Alternative.

In summary, the impacts of the Proposed Action and alternatives on global mean surface temperature, precipitation, or sea-level rise are small in relation to the expected changes associated with the emissions trajectories in the GCAMReference scenario. This is due primarily to the global and multi-sectoral nature of the climate problem. Although these effects are small, they occur on a global scale and are long-lived. The combined impact of these emission reductions with emission reductions from other sources can have large health, societal, and environmental benefits.

5.4.1.3.5 Climate Sensitivity Variations

Using the methodology discussed in Section 5.3.3.4, NHTSA examined the sensitivity of projected climate effects to key technical or scientific assumptions used in the analysis. This examination included modeling the impact of various climate sensitivities on the climate effects under the No Action Alternative and the Preferred Alternative using the GCAMReference scenario. Tables 5.4.1-10-A and 5.4.1-10-B list the results from the sensitivity analysis, which included climate sensitivities of 1.5, 2.0, 2.5, 3.0, 4.5, and 6.0 °C for a doubling of CO_2 in relation to pre-industrial atmospheric concentrations (280 ppm CO_2) (*see* Section 5.3.3.4).

As the tables show, varying climate sensitivities (the equilibrium warming that occurs at a doubling of CO_2 from pre-industrial levels) can affect not only estimated warming, but also estimated sea-level rise and CO_2 concentration. This complex set of interactions occurs because sea level is influenced by temperature, while atmospheric CO_2 concentrations are affected by temperature-dependent effects of ocean carbon storage (specifically, higher temperatures result in lower aqueous solubility of CO_2). Therefore, as Table 5.4.1-10-A and 5.4.1-10-B show, projected future atmospheric CO_2 concentrations differ with varying climate sensitivities even under the same alternative, despite the fact that CO_2 emissions are fixed under each alternative.

Simulated atmospheric CO_2 concentrations in 2040, 2060, and 2100 are a function of changes in climate sensitivity. The small changes in concentration are due primarily to small changes in the aqueous solubility of CO_2 in ocean water: slightly warmer air and sea surface temperatures lead to less CO_2 being dissolved in the ocean and slightly higher atmospheric concentrations.

Table 5.4.1-10-A. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level Rise for Varying Climate Sensitivities for Selected Alternatives,[a,b] Analysis A

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
1 - No Action	1.5	474.799	554.704	757.689	0.722	1.090	1.761	22.80
	2.0	476.307	558.054	767.456	0.901	1.369	2.240	28.27
	2.5	477.628	561.047	776.499	1.055	1.615	2.673	33.10
	3.0	478.795	563.731	784.869	1.191	1.833	3.064	37.40
	4.5	481.584	570.317	806.467	1.511	2.356	4.037	47.81
	6.0	483.620	575.277	823.757	1.741	2.741	4.780	55.59
3 - Preferred	1.5	474.334	553.451	754.750	0.721	1.087	1.754	22.74
	2.0	475.841	556.793	764.468	0.899	1.365	2.232	28.20
	2.5	477.162	559.779	773.465	1.054	1.610	2.663	33.02
	3.0	478.327	562.457	781.793	1.189	1.828	3.053	37.30
	4.5	481.115	569.028	803.286	1.509	2.350	4.023	47.69
	6.0	483.150	573.977	820.492	1.739	2.734	4.764	55.45
Reduction Under the Preferred Alternative Compared to the No Action Alternative								
	1.5	0.465	1.253	2.939	0.001	0.003	0.007	0.06
	2.0	0.466	1.261	2.988	0.001	0.004	0.008	0.07
	2.5	0.466	1.268	3.034	0.002	0.005	0.010	0.08
	3.0	0.468	1.274	3.076	0.002	0.005	0.011	0.10
	4.5	0.469	1.289	3.181	0.002	0.006	0.014	0.12
	6.0	0.470	1.300	3.265	0.002	0.007	0.015	0.14

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.
b. The effects on climate change indicators shown in this table incorporate emission reductions that occur before 2017 due to early compliance with the rulemaking.
c. The values for global mean surface temperature and sea-level rise are relative to levels in 1990.

Table 5.4.1-10-B. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level Rise for Varying Climate Sensitivities for Selected Alternatives,[a,b] Analysis B

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
1 - No Action	1.5	474.799	554.704	757.689	0.722	1.090	1.761	22.80
	2.0	476.307	558.054	767.456	0.901	1.369	2.240	28.27
	2.5	477.628	561.047	776.499	1.055	1.615	2.673	33.10
	3.0	478.795	563.731	784.869	1.191	1.833	3.064	37.40
	4.5	481.584	570.317	806.467	1.511	2.356	4.037	47.81
	6.0	483.620	575.277	823.757	1.741	2.741	4.780	55.59
3 - Preferred	1.5	474.400	553.876	756.168	0.721	1.088	1.757	22.76
	2.0	475.906	557.220	765.907	0.899	1.366	2.236	28.23
	2.5	477.227	560.208	774.922	1.054	1.612	2.667	33.05
	3.0	478.393	562.887	783.266	1.189	1.829	3.058	37.34
	4.5	481.181	569.462	804.802	1.509	2.352	4.029	47.74
	6.0	483.216	574.413	822.041	1.739	2.736	4.771	55.50
Reduction Under the Preferred Alternative Compared to the No Action Alternative								
	1.5	0.399	0.828	1.521	0.001	0.002	0.004	0.04
	2.0	0.401	0.834	1.549	0.001	0.003	0.004	0.04
	2.5	0.401	0.839	1.577	0.001	0.003	0.005	0.05
	3.0	0.402	0.844	1.603	0.002	0.004	0.006	0.06
	4.5	0.403	0.855	1.665	0.002	0.004	0.008	0.07
	6.0	0.404	0.864	1.716	0.002	0.005	0.009	0.09

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.
b. The effects on climate change indicators shown in this table incorporate emission reductions that occur before 2017 due to early compliance with the rulemaking.
c. The values for global mean surface temperature and sea-level rise are relative to levels in 1990.

The response of simulated global mean surface temperatures to variation in the climate sensitivity parameter varies among the years 2040, 2060, and 2100, as shown in Tables 5.4.1-10-A and 5.4.1-10-B. In 2040, the impact of assumed variation in climate sensitivity is low, due primarily to the limited rate at which the global mean surface temperature increases in response to increases in radiative forcing. In 2100, the impact of variation in climate sensitivity is magnified by the larger change in emissions. In Analysis A, the reduction in 2100 global mean surface temperature from the No Action Alternative to the Preferred Alternative ranges from 0.007 °C (0.013 °F) for the 1.5 °C (2.7 °F) climate sensitivity to 0.015 °C (0.027 °F) for the 6.0 °C (10.8 °F) climate sensitivity. In Analysis B, the reduction in 2100 global mean surface temperature from the No Action Alternative to the Preferred Alternative ranges from 0.004 °C (0.007 °F) for the 1.5 °C (2.7 °F) climate sensitivity to 0.009 °C (0.016 °F) for the 6.0 °C (10.8 °F) climate sensitivity.

The sensitivity of the simulated sea-level rise to change in climate sensitivity and global GHG emissions mirrors that of global temperature, as shown in Tables 5.4.1-10-A and 5.4.1-10-B. Scenarios with lower climate sensitivities show generally smaller increases in sea-level rise; at the same time, the reduction in the increase in sea-level rise is lower under the Preferred Alternative than under the No Action Alternative. Conversely, scenarios with higher climate sensitivities have higher projected sea-level rise; again, however, the reduction in the increase of sea-level rise is greater under the Preferred Alternative compared to the No Action Alternative. The range in reduction of sea-level rise under the Preferred Alternative compared to the No Action Alternative is 0.06 to 0.14 centimeter (0.024 to 0.055 inch) in Analysis A and 0.04 to 0.09 centimeter (0.016 to 0.035 inch) in Analysis B, depending on the assumed climate sensitivity.

5.4.2 Cumulative Impacts

The cumulative impacts climate analysis is broader than the corresponding direct and indirect impacts analysis in Section 5.4.1, because this section addresses the effects of the proposed standards together with those of past, present, and reasonably foreseeable future actions.

5.4.2.1 Greenhouse Gas Emissions

NHTSA estimated the emissions resulting from the proposed MY 2017–2025 CAFE standards using the methodologies described in Section 5.3. GHG emissions from MY 2061–2100 passenger cars and light trucks were then scaled using GCAM assumptions regarding the projected growth of U.S. transportation fuel consumption (*see* Section 5.3.1).

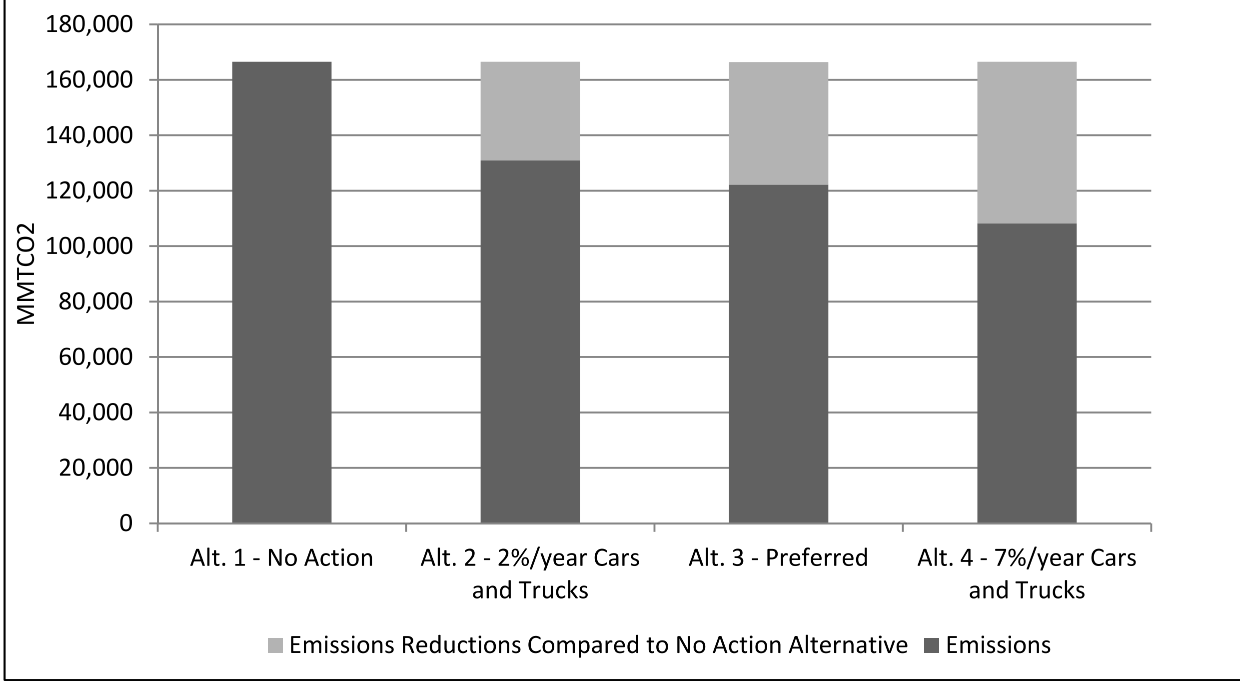
Cumulative emission reductions from each action alternative increase with the increasing stringency of the alternatives, with Alternative 2 having the lowest cumulative emission reductions and Alternative 4 having the highest cumulative emission reductions. Table 5.4.2-1 and Figure 5.4.2-1 show total GHG emissions and emission reductions projected to result from new U.S. passenger cars and light trucks from 2017–2100 under each action alternative. Between 2017 and 2100, projections of cumulative emission reductions due to the Proposed Action and other reasonably foreseeable future actions range from 35,600 to 58,300 $MMTCO_2$. Compared to cumulative global emissions of 4,190,614 $MMTCO_2$ over this period (projected by the GCAM6.0 scenario), the incremental impact of this rulemaking is expected to reduce global CO_2 emissions by about 0.8 to 1.4 percent from their projected levels under the No Action Alternative.

Table 5.4.2-1. CO_2 Emissions and Emission Reductions ($MMTCO_2$) from 2017 through 2100 by Alternative,[a] Cumulative Impacts

Alternative	Total Emissions	Emission Reductions Compared to the No Action Alternative	Percent Emission Reductions Compared to No Action Alternative Emissions
1 - No Action	166,500		
2 - 2%/year Cars and Trucks	130,900	35,600	21%
3 - Preferred	122,200	44,200	27%
4 - 7%/year Cars and Trucks	108,200	58,300	35%

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.

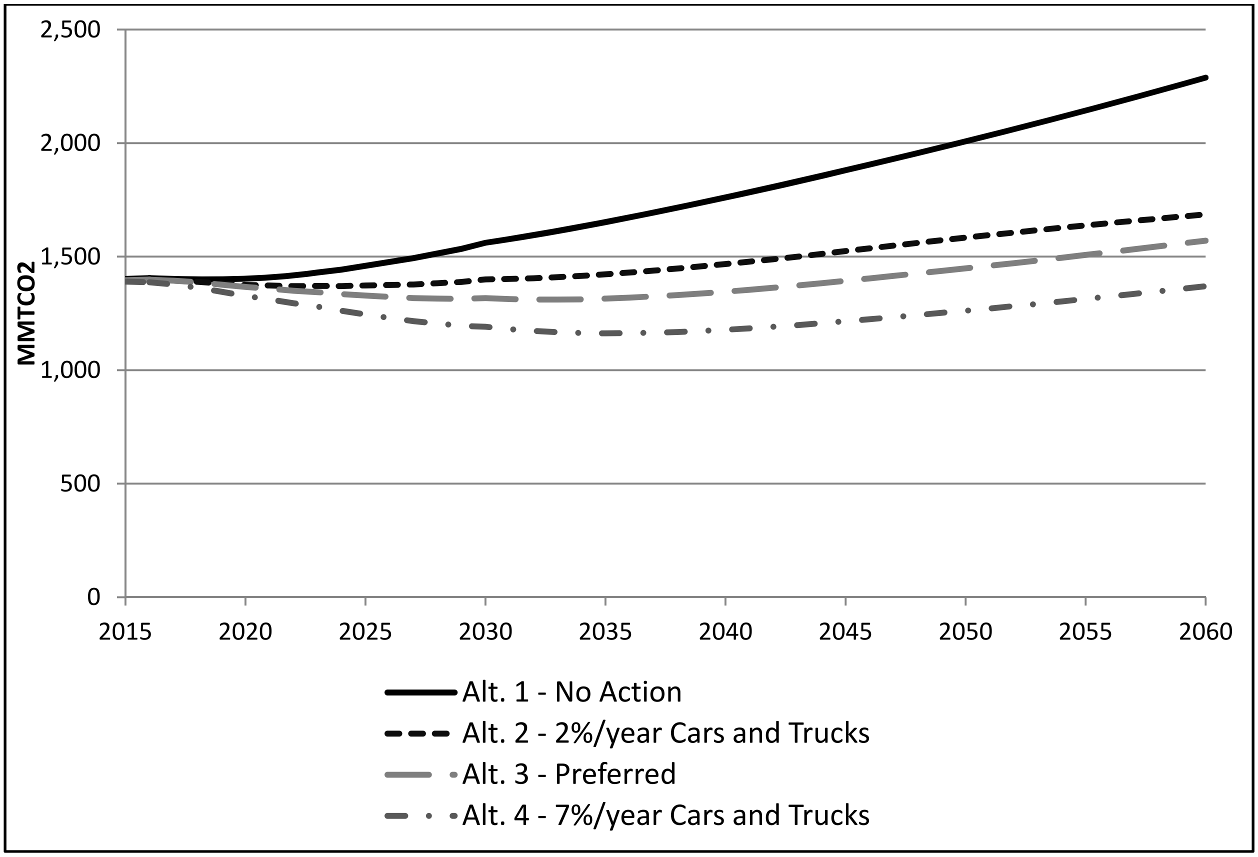
Figure 5.4.2-1. CO_2 Emissions and Emission Reductions ($MMTCO_2$) from 2017 through 2100 by Alternative, Cumulative Impacts



To illustrate the relative impact of these reductions, it can be helpful to consider the magnitude of U.S. emissions from passenger cars and light trucks and to compare them to total U.S. emissions from all sources. Light-duty vehicles in the United States currently account for approximately 20.2 percent of U.S. CO_2 emissions. With the action alternatives reducing U.S. passenger car and light truck CO_2 emissions by 21 to 35 percent over the period 2017 through 2100 under the cumulative impacts analysis presented in this chapter, the Proposed Action would contribute to reducing total U.S. CO_2 emissions in relation to the No Action Alternative. Compared to total U.S. CO_2 emissions from all sources in 2100 projected by the GCAM6.0 scenario of 4,401 $MMTCO_2$ (Clarke et al. 2007), the action alternatives and reasonably foreseeable future increases in fuel economy would reduce total U.S. CO_2 emissions by 12.6 to 19.3 percent in 2100. Figure 5.4.2-2 shows projected annual emissions from U.S. passenger cars and light trucks for MY 2017–2025 taken together with reasonably foreseeable future actions.

As described in Section 5.4.1.1, these emission reductions can also be compared to existing programs designed to reduce GHG emissions in the United States. By comparison, the proposed standards are expected to reduce cumulative CO_2 emissions by 367 to 959 $MMTCO_2$ between 2017 and 2025 (depending on alternative), with emissions levels representing a 6 to 17 percent reduction from the baseline emissions of U.S. passenger cars and light trucks in 2025.

Figure 5.4.2-2. Annual CO_2 Emissions from U.S. Passenger Cars and Light Trucks under the MY 2017–2025 Standards ($MMTCO_2$), Cumulative Impacts



As Table 5.4.2-2 shows, CO_2 emissions from the light-duty vehicle fleet in the United States are projected to increase substantially from their levels in 2017 under the No Action Alternative, which assumes increases in both the number of light-duty vehicles and in VMT per vehicle. The table also shows that each action alternative would reduce total light-duty vehicle CO_2 emissions in future years significantly from their projected levels under the No Action Alternative. Progressively larger reductions in CO_2 emissions from the levels under the No Action Alternative are projected to occur during each future year through 2100, due to decreased fuel consumption as the fleet turns over.

For the cumulative impacts analysis, under each alternative analyzed, growth in the number of passanger cars and light trucks in use throughout the United States, combined with assumed increases in their average use, is projected to result in growth of light-duty vehicle travel. This growth in VMT more than offsets the effect of improvements in fuel economy under Alternative 2 and the Preferred Alternative, resulting in projected increases above present levels in total fuel consumption by light-duty vehicles in the United States over the long term. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from light-duty vehicles. However, the NHTSA anticipates reduced annual fuel consumption and CO_2 emissions from present levels in the short term under these alternatives. Under Alternative 4, increases in fuel economy are expected to result in fuel consumption and CO_2 emission levels through and beyond 2060 that are lower than present annual CO_2 emission levels.

Table 5.4.2-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year),[a] Cumulative Impacts

GHG and Year	Alternative 1 No Action	Alternative 2 2%/Year Cars and Trucks	Alternative 3 Preferred	Alternative 4 7%/Year Cars and Trucks
Carbon Dioxide (CO_2)				
2020	1,402	1,375	1,366	1,327
2040	1,761	1,467	1,346	1,178
2060	2,289	1,686	1,571	1,369
2080	2,272	1,674	1,560	1,360
2100	2,114	1,557	1,451	1,265
Methane (CH_4)				
2020	5.18	5.10	5.08	5.00
2040	6.90	6.11	6.08	5.88
2060	8.99	7.34	7.50	7.38
2080	8.93	7.29	7.45	7.33
2100	8.30	6.78	6.93	6.82
Nitrous oxide (N_2O)				
2020	7.23	7.23	7.23	7.16
2040	8.07	8.11	7.72	6.52
2060	10.54	10.72	10.15	8.46
2080	10.47	10.64	10.08	8.40
2100	9.73	9.90	9.37	7.81

a. $MMTCO_2e$ = million metric tons carbon dioxide equivalent.

Emissions of CO_2 (the primary gas that drives climate effects) from the U.S. light-duty vehicle fleet represented approximately 3.5 percent of total global emissions of CO_2 in 2005 (EPA 2011g, WRI 2011).[58] Although substantial, this source is still a small percentage of global emissions. The proportion of global CO_2 emissions attributable to light-duty vehicles is expected to decline in the future, due primarily to rapid growth of emissions from developing economies (which are, in turn, due in part to growth in global transportation sector emissions).

5.4.2.2 Social Cost of Carbon

The SCC is an estimate of the monetized climate-related damages associated with an incremental increase in annual carbon emissions. *See* Section 5.3.2 for a description of the methodology used to estimate the monetized damages associated with CO_2 emissions and the reductions in those damages that would be attributable to each alternative, including the No Action Alternative.

Table 5.4.2-3 presents the cumulative impacts of the proposed standards, in terms of reduced monetized damages. By applying each future year's SCC estimate to the estimated reductions in CO_2 emissions during that year for each scenario, discounting the resulting figure to its present value, and summing those estimates for each year from 2017 to 2050, NHTSA derived the net present value of the benefits in 2011 (Table 5.4.2-3). For internal consistency, the annual benefits are discounted to net present value terms using the same discount rate as each

[58] Includes land-use change and forestry and excludes international bunker fuels.

SCC estimate (i.e., 5 percent, 3 percent, and 2.5 percent), rather than the 3 percent and 7 percent discount rates applied to other future benefits.[59] Consistent with the SCC tables in Section 5.4.1.2 (Tables 5.4.1-3-A and 5.4.1-3-B), these estimates show increasing benefits with decreasing discount rates (and higher damage estimates). The estimated net present value for a given alternative varies by approximately an order of magnitude across the discount rates. The estimated net present value computed using a single discount rate differs by roughly a factor of three across alternatives.

Table 5.4.2-3. Reduced Monetized Damages of Climate Change for each Action Alternative Net Present Value in 2011 of CO_2 Emission Reductions between 2017 and 2050 (in millions of 2009 dollars), Cumulative Impacts

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
2 - 2%/year Cars and Trucks	$21,426	$116,585	$200,014	$354,725
3 - Preferred	$30,434	$165,104	$283,080	$502,395
4 - 7%/year Cars and Trucks	$44,212	$238,462	$408,379	$725,765

5.4.2.3 Cumulative Impacts on Climate Change Indicators

Using the methodology described in Chapter 2 and Section 5.3.3.2.2, Sections 5.4.2.3.1 through 5.4.2.3.4 describe the cumulative impacts of the alternatives on climate change in terms of atmospheric CO_2 concentrations, temperature, precipitation, and sea-level rise. Section 5.4.2.3.5 presents a sensitivity analysis of the results. The impacts of the Proposed Action and alternatives, in combination with other reasonably foreseeable future actions, on global mean surface temperature, sea-level rise, and precipitation are relatively small in the context of the expected changes associated with the emissions trajectories in the GCAM scenarios.[60] Although relatively small, primarily due to the global and multi-sectoral nature of the climate problem, the impacts occur on a global scale and are long-lived.

5.4.2.3.1 Atmospheric CO_2 Concentrations

MAGICC 5.3.v2 is a simple climate model that is well calibrated to the mean of the multi-model ensemble results for three of the most commonly used emissions scenarios – B1 (low), A1B (medium), and A2 (high) from the IPCC SRES series.

The GCAM6.0 scenario, described in Section 5.3.3.2 was used to represent the No Action Alternative in the MAGICC runs for this EIS. Table 5.4.2-4 and Figures 5.4.2-3 through 5.4.2-6 show the mid-range results of MAGICC model simulations for the No Action Alternative and the three action alternatives for CO_2 concentrations and increase in global mean surface temperature in 2040, 2060, and 2100. As Figures 5.4.2-3 and 5.4.2-4 show, the action alternatives produce a reduction in the increase in projected CO_2 concentration and

[59] Other benefits or costs of proposed regulations unrelated to CO_2 emissions could be discounted at rates that differ from those used to develop the SCC estimates.

[60] These conclusions are not meant to express the view that impacts on global mean surface temperature, precipitation, or sea-level rise are not areas of concern for policymakers. Under NEPA, the agency is obligated to discuss "the environmental impact[s] of *the proposed action.*" 42 U.S.C. § 4332(2)(C)(i) (emphasis added). This analysis fulfills NHTSA's obligations in this regard.

temperature, but the reduction is a small fraction of the total increase in CO_2 concentrations and global mean surface temperature.

As shown in Table 5.4.2-4 and Figures 5.4.2-3 through 5.4.2-4, the band of estimated CO_2 concentrations as of 2100 is fairly narrow, from 672.4 ppm under Alternative 4 to 677.8 ppm under the No Action Alternative. For 2040 and 2060, the corresponding ranges are even smaller. Because CO_2 concentrations are the key driver of all other climate effects, the small changes in CO_2 leads to small differences in climate effects.

Table 5.4.2-4. CO_2 Concentrations, Global Mean Surface Temperature Increase, and Sea-level Rise Using MAGICC (GCAM6.0) by Alternative,[a,b] Cumulative Impacts

Alternative	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-Level Rise (cm)[c]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100
1 - No Action	471.7	543.4	677.8	1.114	1.666	2.564	10.84	17.73	33.42
2 - 2%/year Cars and Trucks	471.4	542.2	674.5	1.113	1.661	2.551	10.84	17.71	33.32
3 - Preferred	471.2	541.8	673.7	1.112	1.659	2.548	10.83	17.70	33.29
4 - 7%/year Cars and Trucks	471.0	541.2	672.4	1.111	1.657	2.542	10.83	17.68	33.24
Reductions Under Alternatives									
2 - 2%/year Cars and Trucks	0.3	1.2	3.3	0.001	0.005	0.013	0.00	0.02	0.10
3 - Preferred	0.5	1.6	4.1	0.002	0.006	0.016	0.01	0.03	0.13
4 - 7%/year Cars and Trucks	0.8	2.2	5.4	0.003	0.009	0.022	0.01	0.05	0.18

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.
b. The effects on climate change indicators shown in this table incorporate emission reductions that occur before 2017 due to early compliance with the rulemaking.
c. The values for global mean surface temperature and sea-level rise relate to 1990.

Figure 5.4.2-3. CO_2 Concentrations (ppm), Cumulative Impacts

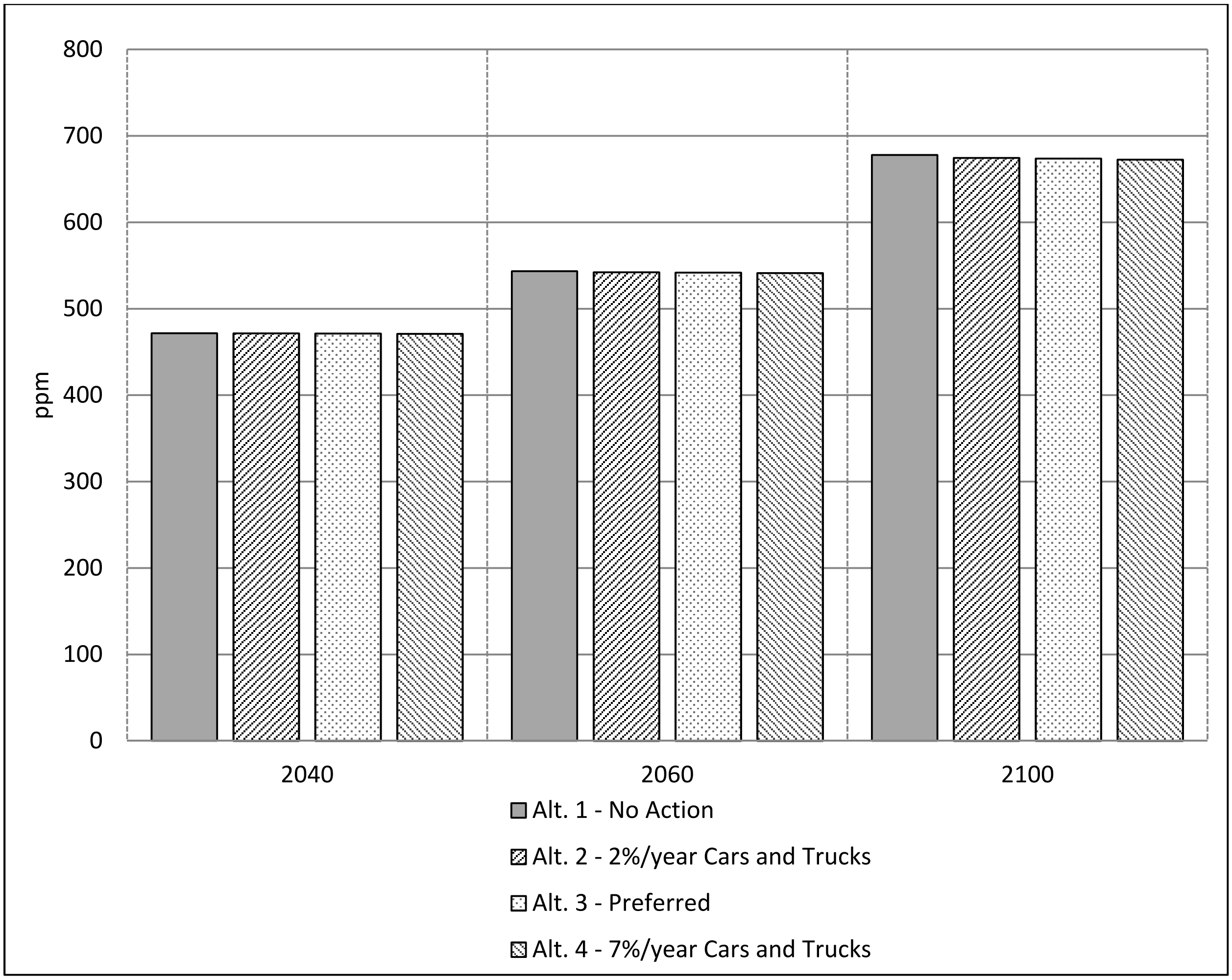
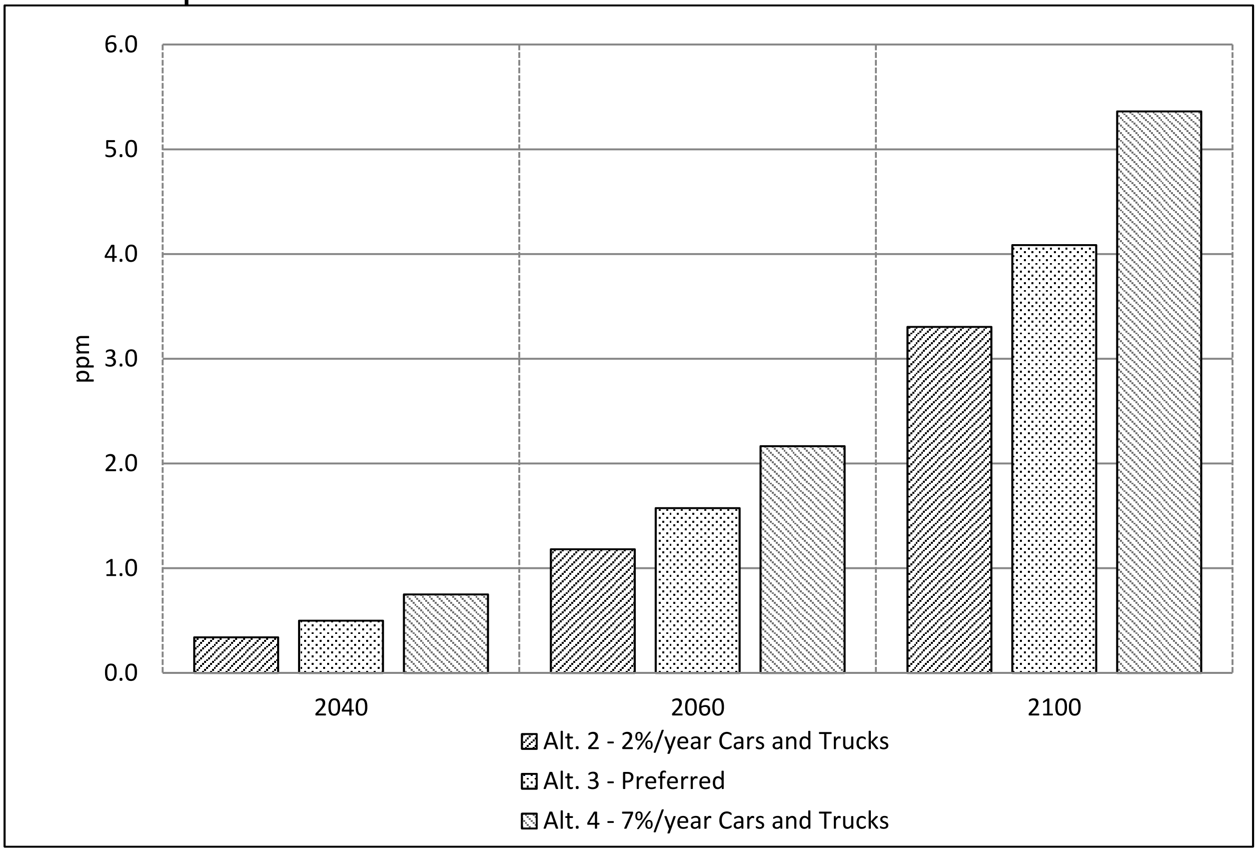


Figure 5.4.2-4. CO_2 Concentrations (ppm) (Reduction Compared to the No Action Alternative), Cumulative Impacts

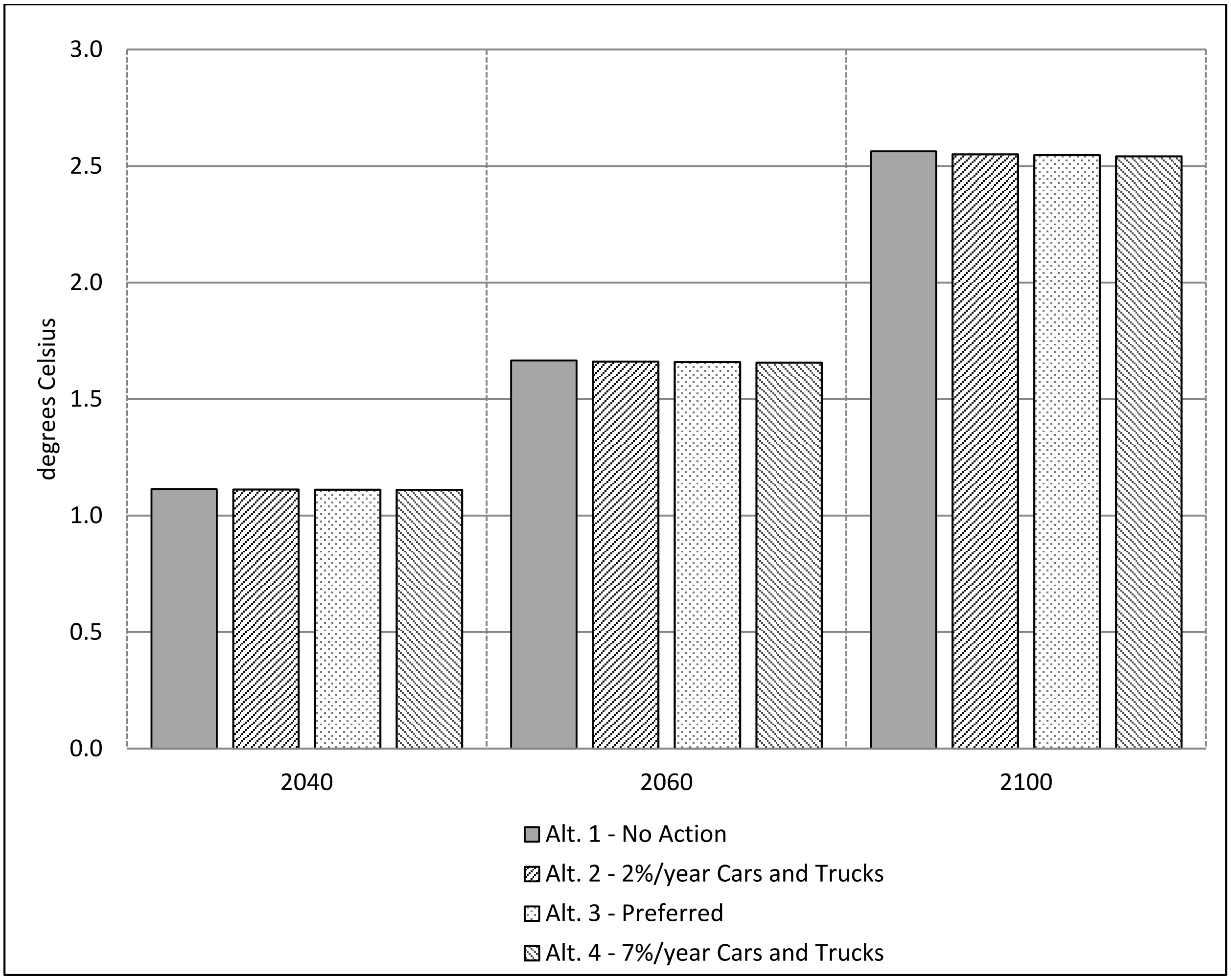


5.4.2.3.2 Temperature

MAGICC simulations of mean global surface air temperature increases are shown in Table 5.4.2-4. Under the No Action Alternative, the cumulative global mean surface temperature is projected to increase by 1.11 °C (2.01 °F) by 2040, 1.67 °C (2.99 °F) by 2060, and 2.56 °C (4.62 °F) by 2100.[61] The differences among alternatives are small. For example, in 2100 the reduction in temperature increase under the action alternatives in relation to the No Action Alternative ranges from approximately 0.013 °C (0.023 °F) under Alternative 2 to 0.022 °C (0.040 °F) under Alternative 4.

Quantifying the changes to regional climate from the Proposed Action and alternatives is not possible at this point due to the limitations of existing climate models. However, the alternatives would be expected to reduce the changes in relation to the reduction in global mean surface temperature. Regional changes to warming and seasonal temperatures as described in the IPCC Fourth Assessment Report are summarized in Table 5.4.1-6.

Figure 5.4.2-5. Global Mean Surface Temperature Increase (°C), Cumulative Impacts



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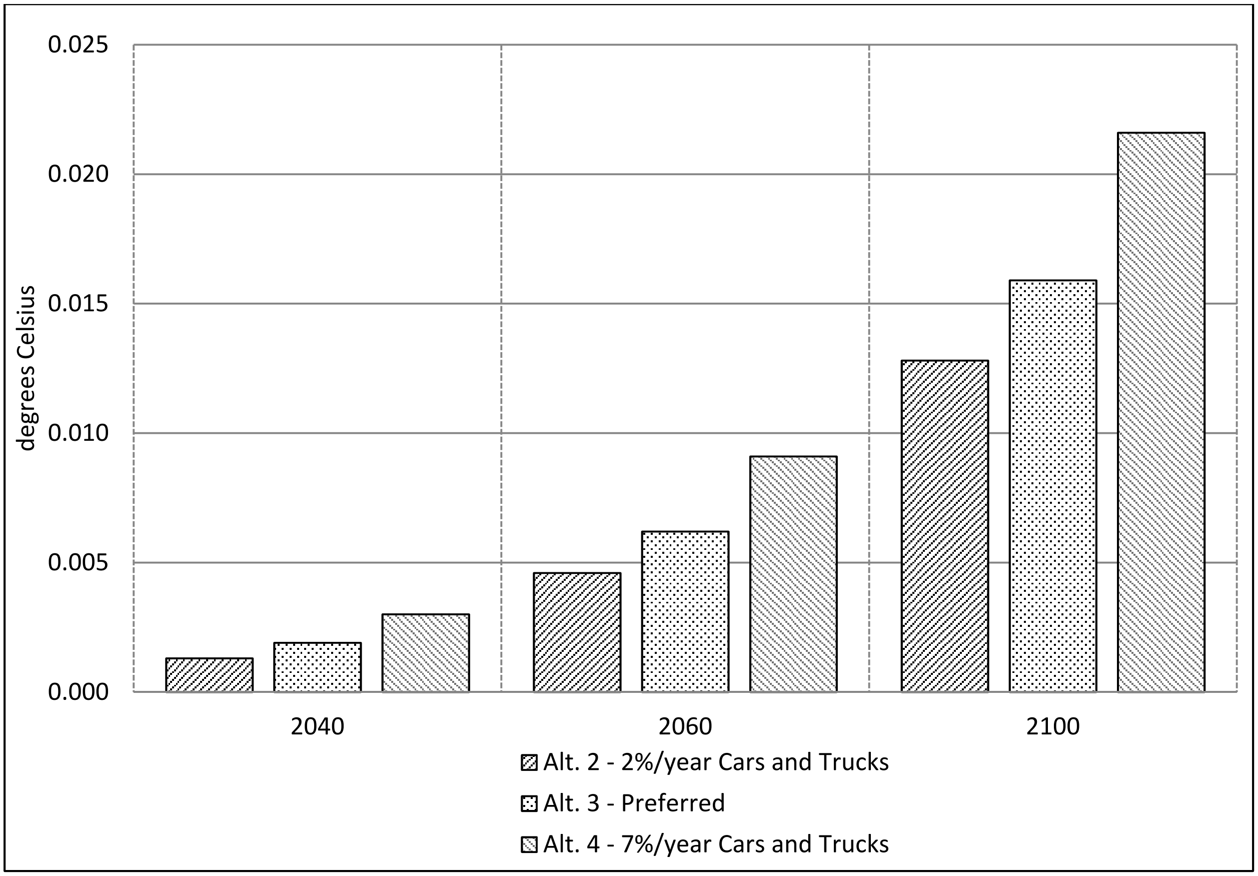
61 Because the actual increase in global mean surface temperature lags the commitment to warming, the impact on global mean surface temperature increase is less than the impact on the long-term commitment to warming. The actual increase in surface temperature lags the commitment due primarily to the time required to heat the oceans.

Figure 5.4.2-6. Reduction in Global Mean Temperature Compared to the No Action Alternative, Cumulative Impacts



5.4.2.3.3 Precipitation

The effects of higher temperatures on the amount of precipitation and the intensity of precipitation events, as well as the IPCC scaling factors to estimate global mean precipitation change, are discussed in Section 5.4.1.3.3. Applying these scaling factors to the reductions in global mean surface warming provides estimates of changes in global mean precipitation. Given that the action alternatives would reduce temperature increases slightly in relation to the No Action Alternative, they also would reduce predicted increases in precipitation slightly, as shown in Table 5.4.2-5.

Table 5.4.2-5. Global Mean Precipitation (percent Increase) Based on GCAM6.0 Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC,[a] Cumulative Impacts

Scenario	2020	2055	2090
Global Mean Precipitation Change (scaling factor, % change in precipitation per °C change in temperature)	1.45	1.51	1.63
Global Temperature Above Average 1980–1999 Levels (°C) for the GCAM6.0 Scenario by Alternative			
Alternative 1 - No Action	0.583	1.533	2.386
Alternative 2 - 2%/year Cars and Trucks	0.583	1.529	2.375
Alternative 3 - Preferred	0.583	1.528	2.372
Alternative 4 - 7%/year Cars and Trucks	0.583	1.526	2.367
Reduction in Global Temperature (°C) by Alternative3, Mid-level Results (Compared to the No Action Alternative)[b]			
Alternative 2 - 2%/year Cars and Trucks	0.000	0.003	0.011
Alternative 3 - Preferred	0.000	0.005	0.014
Alternative 4 - 7%/year Cars and Trucks	0.000	0.007	0.019
Global Mean Precipitation Increase (%)			
Alternative 1 - No Action	0.85%	2.31%	3.89%
Alternative 2 - 2%/year Cars and Trucks	0.85%	2.31%	3.87%
Alternative 3 - Preferred	0.85%	2.31%	3.87%
Alternative 4 - 7%/year Cars and Trucks	0.85%	2.30%	3.86%
Reduction in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alternative 2 - 2%/year Cars and Trucks	0.00%	0.01%	0.02%
Alternative 3 - Preferred	0.00%	0.01%	0.02%
Alternative 4 - 7%/year Cars and Trucks	0.00%	0.01%	0.03%

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.
b. Precipitation change in 2020 is not zero, but is smaller than the precision being reported.

Regional variations and changes in the intensity of precipitation events cannot be quantified further. This inability is due primarily to the lack of availability of atmospheric-ocean general circulation models (AOGCMs) required to estimate these changes. AOGCMs are typically used to provide results among scenarios having very large changes in emissions such as the SRES B1 (low), A1B (medium), and A2 (high) scenarios; very small changes in emissions profiles produce results that would be difficult to resolve. Also, the various AOGCMs produce results that are regionally consistent in some cases but inconsistent in others.

Quantifying the changes in regional climate from the action alternatives is not possible at this point, but the action alternatives would reduce the changes in relation to the reduction in global mean surface temperature. Regional changes to precipitation as described by the IPCC Fourth Assessment Report are summarized in Table 5.4.1-6 in Section 5.4.1.3.2.

5.4.2.3.4 Sea-level Rise

The components of sea-level rise, MAGICC 5.3.v2 treatment of these components, and recent scientific assessments are discussed in Section 5.4.1.3.4. Table 5.4.2-4 presents the impact on sea-level rise from the scenarios and shows sea-level rise in 2100 ranging from 33.42 centimeters (13.15 inches) under the No Action Alternative to 33.24 centimeters (13.09 inches) under Alternative 4, for a maximum reduction of 0.18 centimeter (0.07 inch) by 2100.

5.4.2.3.5 Climate Sensitivity Variations

NHTSA examined the sensitivity of climate effects on key assumptions used in the analysis. This examination reviewed the impact of various climate sensitivities and global emissions scenarios on the climate effects under the No Action Alternative and the Preferred Alternative. Table 5.4.2-6 presents the results from the sensitivity analysis.

Table 5.4.2-6. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level Rise for Varying Climate Sensitivities for Selected Alternatives,[a,b] Cumulative Impacts

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Emissions Scenario: RCP4.5								
Totals								
1 - No Action	1.5	457.837	499.180	505.171	0.633	0.869	0.981	16.57
	2.0	459.231	502.018	511.117	0.793	1.101	1.284	20.71
	2.5	460.457	504.567	516.683	0.933	1.309	1.568	24.43
	3.0	461.543	506.860	521.878	1.057	1.494	1.831	27.77
	4.5	464.147	512.511	535.430	1.351	1.946	2.512	36.00
	6.0	466.054	516.785	546.399	1.564	2.282	3.053	42.26
3 - Preferred	1.5	457.340	497.648	501.572	0.631	0.864	0.969	16.47
	2.0	458.733	500.477	507.459	0.791	1.096	1.270	20.59
	2.5	459.958	503.018	512.972	0.932	1.303	1.551	24.29
	3.0	461.043	505.304	518.119	1.055	1.488	1.812	27.61
	4.5	463.645	510.939	531.549	1.349	1.938	2.488	35.81
	6.0	465.551	515.201	542.423	1.562	2.273	3.026	42.04

Table 5.4.2-6. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level Rise for Varying Climate Sensitivities for Selected Alternatives,[a,b] Cumulative Impacts (continued)

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Reduction Under the Preferred Alternative Compared to the No Action Alternative								
	1.5	0.497	1.532	3.599	0.001	0.004	0.012	0.10
	2.0	0.498	1.541	3.658	0.002	0.005	0.015	0.12
	2.5	0.499	1.549	3.711	0.002	0.006	0.017	0.14
	3.0	0.500	1.556	3.759	0.002	0.007	0.019	0.16
	4.5	0.502	1.572	3.881	0.002	0.008	0.023	0.19
	6.0	0.503	1.584	3.976	0.002	0.009	0.027	0.22
Emissions Scenario: GCAM6.0								
Totals								
1 - No Action	1.5	467.902	535.064	655.076	0.671	0.983	1.443	20.25
	2.0	469.342	538.148	663.231	0.839	1.238	1.852	25.17
	2.5	470.608	540.909	670.797	0.985	1.465	2.224	29.53
	3.0	471.725	543.388	677.811	1.114	1.666	2.564	33.42
	4.5	474.403	549.482	695.946	1.418	2.152	3.417	42.91
	6.0	476.362	554.079	710.493	1.638	2.510	4.077	50.02
3 - Preferred	1.5	467.405	533.512	651.160	0.670	0.978	1.434	20.16
	2.0	468.844	536.587	659.253	0.838	1.233	1.839	25.06
	2.5	470.108	539.340	666.763	0.984	1.459	2.210	29.41
	3.0	471.225	541.812	673.725	1.112	1.659	2.548	33.29
	4.5	473.901	547.890	691.729	1.416	2.144	3.397	42.74
	6.0	475.859	552.474	706.173	1.636	2.502	4.054	49.83
Reduction Under the Preferred Alternative Compared to the No Action Alternative								
	1.5	0.497	1.552	3.916	0.001	0.004	0.010	0.09
	2.0	0.498	1.561	3.978	0.001	0.005	0.012	0.11
	2.5	0.500	1.569	4.034	0.002	0.006	0.014	0.12
	3.0	0.500	1.576	4.086	0.002	0.006	0.016	0.13
	4.5	0.502	1.592	4.217	0.002	0.007	0.020	0.17
	6.0	0.503	1.605	4.320	0.002	0.008	0.023	0.19

Table 5.4.2-6. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level Rise for Varying Climate Sensitivities for Selected Alternatives,[a,b] Cumulative Impacts (continued)

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Emissions Scenario: GCAMReference								
Totals								
1 - No Action	1.5	474.799	554.704	757.689	0.722	1.090	1.761	22.80
	2.0	476.307	558.054	767.456	0.901	1.369	2.240	28.27
	2.5	477.628	561.047	776.499	1.055	1.615	2.673	33.10
	3.0	478.795	563.731	784.869	1.191	1.833	3.064	37.40
	4.5	481.584	570.317	806.467	1.511	2.356	4.037	47.81
	6.0	483.620	575.277	823.757	1.741	2.741	4.780	55.59
3 - Preferred	1.5	474.302	553.139	753.605	0.721	1.086	1.752	22.72
	2.0	475.808	556.480	763.309	0.899	1.364	2.229	28.17
	2.5	477.129	559.465	772.291	1.054	1.610	2.660	32.99
	3.0	478.294	562.142	780.606	1.189	1.827	3.049	37.27
	4.5	481.082	568.711	802.067	1.509	2.349	4.019	47.65
	6.0	483.117	573.658	819.247	1.739	2.733	4.759	55.41
Reduction Under the Preferred Alternative Compared to the No Action Alternative								
	1.5	0.497	1.565	4.084	0.001	0.004	0.009	0.08
	2.0	0.499	1.574	4.147	0.001	0.005	0.011	0.10
	2.5	0.499	1.582	4.208	0.002	0.006	0.013	0.11
	3.0	0.501	1.589	4.263	0.002	0.006	0.015	0.13
	4.5	0.502	1.606	4.400	0.002	0.007	0.018	0.16
	6.0	0.503	1.619	4.510	0.002	0.008	0.021	0.18

a. The numbers in this table are rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.
b. The effects on climate change indicators shown in this table incorporate emission reductions that occur before 2017 due to early compliance with the rulemaking.
c. The values for global mean surface temperature and sea-level rise are relative to levels in 1990.

The use of alternative global emissions scenarios can influence the results in several ways. Emission reductions can lead to larger reductions in CO_2 concentrations in later years because more of the anthropogenic emissions are expected to stay in the atmosphere. The use of different climate sensitivities (the equilibrium warming that occurs at a doubling of CO_2 from pre-industrial levels) could affect not only warming but also indirectly affect sea-level rise and CO_2 concentration. Sea level is influenced by temperature. CO_2 concentration is affected by temperature-dependent effects of ocean carbon storage (higher temperature results in lower aqueous solubility of CO_2).

As shown in Table 5.4.2-6, the sensitivity of simulated CO_2 emissions in 2040, 2060, and 2100 to assumptions of global emissions and climate sensitivity is low; stated simply, CO_2

concentration differences do not change much with changes in global emissions and climate sensitivity. For 2040 and 2060, the choice of global emissions scenario has little impact on the results. By 2100, the Preferred Alternative has the greatest impact in the global emissions scenario with the highest CO_2 emissions (GCAMReference scenario) and the least impact in the scenario with the lowest CO_2 emissions (RCP4.5). The total range of the impact of the Preferred Alternative on CO_2 concentrations in 2100 is roughly 3.6 to 4.5 ppm. The Preferred Alternative using the GCAM6.0 scenario and a 3.0 °C (5.4 °F) climate sensitivity has an impact of a 4.1 ppm reduction compared to the No Action Alternative.

The sensitivity of the simulated global mean surface temperatures for 2040, 2060, and 2100 varies over the simulation time period, as shown in Table 5.4.2-6. In 2040, the impact is low due primarily to the rate at which global mean surface temperature increases in response to increases in radiative forcing. In 2100, the impact is large due to climate sensitivity as well as change in emissions. In 2040, the reduction in global mean surface temperature from the No Action Alternative to the Preferred Alternative is 0.001 to 0.002 °C (0.002 to 0.004 °F) across the climate sensitivities and global emissions scenarios, as shown in Table 5.4.2-6. The impact on global mean surface temperature due to assumptions concerning global emissions of GHGs is also important. The scenarios with the higher global emissions of GHGs, such as the GCAMReference scenario, have a lower reduction in global mean surface temperature and the scenarios with lower global emissions have a higher reduction. This is in large part due to the nonlinear and near-logarithmic relationship between radiative forcing and CO_2 concentrations. At high emissions levels, CO_2 concentrations are high; therefore, a fixed reduction in emissions yields a lower reduction in radiative forcing and global mean surface temperature.

The sensitivity of simulated sea-level rise to change in climate sensitivity and global GHG emissions mirrors that of global temperature, as shown in Table 5.4.2-6. Scenarios with lower climate sensitivities have lower increases in sea-level rise; the increase in sea-level rise is lower under the Preferred Alternative than it would be under scenarios with higher climate sensitivities. Conversely, scenarios with higher climate sensitivities have higher sea-level rise; the increase of sea-level rise is higher under the Preferred Alternative than it would be under scenarios with lower climate sensitivities. Higher global GHG emissions scenarios have higher sea-level rise, but the impact of the Preferred Alternative is less than in scenarios with lower global emissions. Conversely, scenarios with lower global GHG emissions have lower sea-level rise, although the impact of the Preferred Alternative is greater than in scenarios with higher global emissions.

5.5 Health, Societal, and Environmental Impacts of Climate Change

5.5.1 Introduction

As described in Section 5.4, ongoing emissions of GHGs from many sectors, including transportation, affect global CO_2 concentrations, temperature, precipitation, and sea level. This section describes how these effects can translate to impacts on key natural and human resources.

Although the action alternatives NHTSA is considering would decrease growth in GHG emissions, they would not prevent climate change; instead, they would result in reductions in the anticipated increases of global CO_2 concentrations, temperature, precipitation, and sea level otherwise projected to occur under the No Action Alternative. NHTSA's assumption is that these reductions in climate effects would be reflected in reduced impacts on affected resources. However, the magnitude of the changes in climate effects that the alternatives would produce (*see* Section 5.4) are too small to address quantitatively in terms of their impacts on the specific resources discussed below.[62] Consequently, the discussion of resource impacts in this section does not distinguish among the alternatives; rather it provides a qualitative review of the benefits of reducing GHG emissions and the magnitude of the risks involved in climate change.[63]

To reduce repetition, this section incorporates by reference Section 4.5 of the MY 2012–2016 CAFE standards Final EIS (NHTSA 2010b) and Section 4.5 of the MY 2014–2018 HD Final EIS (NHTSA 2011b).[64] Both documents can be accessed on the NHTSA Fuel Economy website at http://www.nhtsa.gov/fuel-economy or the Federal Government's online docket at http://www.regulations.gov/ (Docket No. NHTSA-2009-0059-0140 [MY 2012–2016 CAFE standards] and Docket No. NHTSA-2010-0079-0151 [MY 2014–2018 HD vehicle standards]).

This section is divided into discussions of sector-specific impacts of climate change. Specifically, Sections 5.5.2 through 5.5.7 address cumulative impacts on the following key natural and human resources:

- Freshwater resources (the availability, resource management practices, and vulnerabilities of fresh water as a function of climate)
- Terrestrial and freshwater ecosystems (existing and potential vulnerabilities and benefits of the respective species and communities in response to climate change)
- Marine, coastal systems, and low-lying areas (the interplay among climate, environment, species, and communities in coastal and open-ocean waters, including coastal wetlands and coastal human settlements)

[62] Although the projected reductions in CO_2 and climate effects in Section 5.4 are small compared to total projected future climate change, they are quantifiable, directionally consistent, and will contribute to reducing the risks associated with climate change. While NHTSA does quantify the reductions in monetized damages attributable to each action alternative (in the social cost of carbon analysis), many specific impacts on health, society, and the environment (e.g. number of species lost) cannot be estimated quantitatively. Therefore, NHTSA provides a detailed discussion of the impacts of climate change on various resource sectors in this section.
[63] *See* 42 U.S.C. § 4332 (requiring federal agencies to "identify and develop methods and procedures … which will insure that presently unquantified environmental amenities and values may be given appropriate consideration"). *See* CEQ 1997b (recognizing that agencies are sometimes "limited to qualitative evaluations of effects because cause-and-effect relationships are poorly understood" or cannot be quantified).
[64] Under CEQ NEPA implementing regulations, material should be incorporated by reference when the effect is to reduce excessive paperwork without impeding agency or public review. 40 CFR 1502.21.

- Food, fiber, and forest products (the environmental vulnerabilities of farming, forestry, and fisheries to climate change)
- Industries, settlements, and society (how climate change might affect human institutions and systems, including industrial and service sectors; large and small urban areas and rural communities; transportation systems; energy production; and financial, cultural, and social institutions)
- Human health (how a changing climate might affect human mortality and morbidity).

Within each section, the discussion starts with a brief summary of the information in the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS. Each section contains two subsections. The first summarizes recent findings (i.e., findings since publication of the MY 2014–2018 HD Final EIS in June 2011) of the consequences of observed and projected climate change in the United States and globally on each resource, drawing from reports summarizing existing peer-reviewed information and peer-reviewed literature. The second reviews the potential to adapt to climate change, and the extent to which adaptation could reduce climate change risks. In instances where there is no recent literature regarding adaptation, this section is omitted.

Although the approach is systematic, these topics do not exist in isolation, and there is some overlap between discussions. The sections generally reflect the organization of topic areas in the climate literature, notably by the IPCC, a primary source for much of the information in this section. The categories do not match the classification of resources typically found in an EIS, such as biological resources, water resources, land use, or socioeconomics, although these resources are discussed.

To reflect the likelihood of climate change impacts accurately for each sector, NHTSA references and uses the IPCC uncertainty guidelines (*see* Section 5.1.1). This approach provides a consistent methodology to define confidence levels and percent probability of a predicted outcome or impact. More information about the uncertainty guidelines is provided in *Treatment of Uncertainties in the IPCC's Working Group II Assessment* in IPCC (2007a).

This section, like the corresponding sections in the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS, draws from panel-reviewed synthesis and assessment reports from the IPCC, the U.S. Climate Change Science Program, and the U.S. Global Change Research Program. NHTSA similarly relies on panel reports because they have assessed numerous individual studies to draw general conclusions about the state of science and have been reviewed and formally accepted by, commissioned by, or in some cases authored by U.S. Government agencies and individual government scientists. This material has been well vetted, both by the climate change research community and by the U.S. Government. In many cases, it reflects the consensus conclusions of expert authors. This section also references peer-reviewed literature that has not been assessed or synthesized by an expert panel, but which supplements the findings of the panel-reviewed reports.

5.5.2 Freshwater Resources

5.5.2.1 Recent Findings

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on freshwater resources in the United States and globally. For information on previously reported findings, *see* Section 4.5.3 (*Freshwater Resources*) of the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS. The recent findings are drawn primarily from the following major international or national scientific assessment reports: the IPCC *Fourth Assessment Report* (IPCC 2007a, IPCC2007b, IPCC 2007c); National Science and Technology Council's *Scientific Assessment of the Effects of Global Change on the United States* (National Science and Technology Council 2008), Arctic Climate Impact Assessment (ACIA 2005); EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act* (EPA 2009e); National Resource Council's (NRC's) *America's Climate Choices* (NRC 2010d, NRC 2010e); NRC's *Climate Stabilization Targets* (NRC 2010a), and *The Copenhagen Diagnosis* (Allison et al. 2009) authored by 26 climate scientists. Overall, these new studies confirm previous results and add to the growing body of modeling results and field observations that indicate substantial impacts to freshwater resources as a result of climate change.

5.5.2.1.1 Precipitation, Streamflow, Runoff, and Surface Waters

NHTSA's two recent EISs reported model projections indicating that climate change is increasing precipitation extremes. Two new studies support this conclusion with observational data and estimate the contribution of climate change. Min et al. (2011) compared 6,000 observations of precipitation extremes for the period 1951 through 1999 with the World Climate Research Programme Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model simulated precipitation over the same period. The observational data covered most of the Northern Hemisphere land area, including North America and Eurasia. Results confirm that precipitation extremes for two-thirds of the data-covered land areas, measured by the annual maxima of daily precipitation and the 5-day consecutive precipitation amount, intensified over the past half century.

In another recent attribution study, Pall et al. (2011) isolated the contribution of climate change to the probability of a flood event in the United Kingdom in fall 2000. The researchers conducted a large number of model runs of autumn 2000 weather to determine how often the flood event would occur under present-day conditions, and then repeated the experiment under pre-industrial conditions when there was less CO_2 and cooler temperatures. The number of times the flood event occurred under present conditions compared to pre-industrial conditions was an indication of how much more likely the event was because of climate change. Results indicated that the increase in risk due to climate change is "very likely" to be more than 20 percent, and "likely" to be more than 90 percent.

A new study by the U.S. Bureau of Reclamation confirms the regional differences in climate-related changes in U.S. streamflows reported in the previous EISs (Bureau of Reclamation 2011). Consistent with previous findings, the study's analytical and modeling results for eight Reclamation river basins indicate that northwestern and north-central regions of the western United States are becoming wetter, while the southwestern and south-central regions are becoming drier.

The report also found that warming trends have led to more rainfall and less snow during the cool season in a number of locations in the western United States, resulting in less snowpack accumulation in those areas. Snowpack losses are projected to be greatest in low-lying valleys and low-altitude mountains where baseline climate is close to freezing. Projections also indicate that in high-latitude and high-altitude areas (e.g., Columbia headwaters in Canada and Colorado headwaters in Wyoming) there is a chance that snowpack losses could be offset by cool-season precipitation increases.

The study's runoff projections indicate that cool-season runoff will increase over the twenty-first century for river basins along the west coast of the United States (San Joaquin, Sacramento, Truckee, Klamath, and Columbia) and in the north-central United States (Missouri). Over the twenty-first century, a gradual decrease in runoff is projected for the area from the southwestern United States to the southern Rockies Mountains (Colorado River Basin and Rio Grande River Basin).

Warm-season runoff is projected to show significant declines in the Bureau of Reclamation river basins in the area from southern Oregon, the southwestern United States, and the southern Rockies (San Joaquin, Sacramento, Klamath, Truckee, Rio Grande and Colorado). North of this region, in the Columbia and Missouri river basins, little change to a slight increase is expected.

As discussed in the previous EISs, snowpack in western North America has shown significant warming-induced declines in recent decades, and the trend is projected to continue throughout this century. A new study examined snowpack reconstructions from 66 tree-ring chronologies in the major drainages of the northern Rocky Mountains to determine if snowpack declines in this region are within the range of natural variability or result from human-induced climate change. Results indicated that the decline in snowpack in the region is "almost unprecedented" in magnitude over the past 800 years. The dramatic decline in snowpack is especially serious because tens of millions of people rely on water that originates in the region's accumulated snow (Pederson et al. 2011).

The HD Final EIS indicated that warming in the Arctic has proceeded at about twice the rate as elsewhere, leading to decreases in summer sea-ice extent, glacier and ice sheet mass loss, coastal erosion, and permafrost thawing. A recent study found that an additional effect of Arctic warming is the release of toxic chemicals previously held in the area's water, snow, ice, and soils. Persistent organic pollutants are evaporating into the atmosphere above the warming Arctic, where they can recirculate and once again pose a threat to human health and the environment (Ma et al. 2011).

More than half of the world's wetlands are in high northern latitudes where permafrost thawing has a significant influence on wetland dynamics. A new modeling study using the University of Victoria Earth System Climate Model, which includes thermal and hydrological characterization of frozen ground, projects that the area and duration of northern-latitude wetlands declines as permfrost thawing increases under three high-emission scenarios for GHGs. Initially, permafrost thawing creates wetlands, because frozen layers below the upper limit of melting prevent surface moisture from draining into the soil. However, once thawing deepens beyond approximately 1 meter (approximately 3 feet), a significant amount of the near-surface moisture drains to deeper soil layers, reducing the area of wetlands. This finding has important implications for atmospheric concentrations of GHGs, because permafrost regions contain one of the world's largest carbon pools vulnerable to climate change, and CH_4 emissions from wetlands contribute an estimated 20 to 40 percent of total global CH_4 emissions. Modeling results imply that initial warming and permafrost thawing will result in greater release of CO_2 and CH_4 into the atmosphere. But as warming increases and thawing deepens, wetland extent will decline, reducing emissions. The net effect is difficult to predict (Avis et al. 2011).

5.5.2.1.2 Glaciers

Studies discussed in the previous EISs indicate that glaciers are receding worldwide as the climate warms. A new modeling study provides more details on glacier changes. The study simulated glacier volume changes (as percent of initial volume) of more than 120,000 glaciers worldwide in response to twenty-first century temperature and precipitation projections from 10 general circulation models (GCMs). The glacier data were from the World Glacier Inventory. The multi-model mean ranged from 8 to 75 percent volume loss by 2100, with the smallest values in Greenland (8 percent) and High Mountain Asia (10 percent) and the largest values in the European Alps (75 percent) and New Zealand (72 percent). The range in results is similar to the range reported in IPCC (2007d) (Radic and Hock 2011). New observational studies in particular regions, including Canada, South America, Europe, Alaska, and Nepal, also show glacier declines. There has been a significant loss of mass from glaciers in the Canadian Arctic Archipelago, and observations over the past decade indicate that the rate of loss is increasing (Gardner et al. 2011). In South America, there has been a dramatic increase in the melt rate and contribution to sea-level rise of glaciers in the two large Patagonian icefields (Glasser et al. 2011). Glacier retreat has also accelerated in the European Alps. A new analysis of glacial mass balance data for the past century shows that there has been a 13 percent increase in glacial runoff in the Alps during August over the past 2 decades. Modeling results indicate that this region could see a 55 to 85 percent reduction in runoff from glacial melt by the end of this century (Huss 2011).

A new update by the Arctic Monitoring and Assessment Program indicates that the rate of loss of Arctic glaciers has increased over the past decade in most regions. Average snow cover duration is projected to decline by up to 20 percent by 2050 (AMAP 2011). A recent summary shows significant recession among Alaska's many glaciers since the mid 1990s. Biannual observations of the inland Gulkana Glacier and the Wolverine Glacier near the southern coast since 1965 suggest that loss of mass of both glaciers is largely the result of temperature increases (Arendt 2011).

A recent modeling study of the Langtang catchment in Nepal, which is representative of high-altitude glacierized catchments in the central and eastern Himalayas, projected decreases in glacier area of 32 percent by 2035, 50 percent by 2055, and 75 percent by 2088. These findings are important because they indicate that Himalayan glaciers are not likely to disappear as early as 2035, which was suggested in the IPCC Fourth Assessment Report. Projections from the new study also indicate a net increase in stream flow of 4 millimeters (0.16 inches) per year. Modeling results are consistent with observations in the Himalayas showing that rain runoff and base flow are increasing, snow runoff remains more or less constant, and glacier runoff is gradually declining (Immerzeel et al. 2011).

5.5.2.1.3 Extreme Events – Floods and Droughts

The previous EISs observed that droughts will continue to increase in subtropical and mid-latitude regions in response to anthropogenic climate change, and cited a review by Dai (2010) indicating that global aridity has increased substantially since the 1970s due to recent drying over Africa, southern Europe, East and South Asia, and eastern Australia. Now Dai (2011) has considered how trends and model projections might vary using different forms of the Palmer

Drought Severity Index, the most commonly used indicator of drought. Results show that all forms of the index effectively capture trends in streamflow and soil moisture in different regions of the world. Widespread drying from 1950 to 2008 from climate change is observed, confirming the results of studies reported in the previous EISs. The percentage of dry areas worldwide has risen by approximately 1.74 percent per decade over this period, and the trend in aridity suggests even more severe drying over this century (Dai et al. 2011).

Previous EISs also showed that human-induced climate change is leading to drying conditions in the western and southwestern United States. Supporting this conclusion is a new study by Cayan et al. (2010) reporting that the twenty-first century drought in the Colorado River Basin is the most extreme in more than 100 years. Simulations suggest that the rest of the century will see more severe droughts, with some droughts lasting for 12 or more years.

5.5.2.2 Adaptation

Adaptation has received increasing attention in recent years given the magnitude of declines in precipitation and runoff in a number of heavily populated regions, many of which already experience water shortages. In the least-developed countries, water resource changes are an even greater concern due to a lack of water infrastructure to help them adjust to changes in water availability. The ability to change operations and maintenance schedules is an important adaptation mechanism, and in the United States, water utilities are already determining how such adjustments should be made. In countries lacking infrastructure, ecosystem-based adaptation will play an important role, and there are a number of well-established techniques for improving watershed conditions to protect surface water resources and promote groundwater recharge (Colls et al. 2009). Water conservation and demand management are also important tools for managing water supply. Integrated Water Resources Management is another effective approach for protecting water resources that is becoming more common. All of these adaptation measures are commonly referred to as “no regrets” actions, because they are beneficial even without considering climate change; therefore, they are increasingly considered essential for twenty-first century water management.

5.5.3 Terrestrial and Freshwater Ecosystems

5.5.3.1 Recent Findings

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on terrestrial and freshwater ecosystems in the United States and globally. For information on previously reported findings, *see* Section 4.5.4 (*Terrestrial and Freshwater Ecosystems*) of the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS. These findings are drawn primarily from the following major international or national scientific assessment reports: EPA’s *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act* (EPA 2009e); the IPCC *Fourth Assessment Report* (IPCC 2007a, 2007b, 2007c); the U.S. Climate Change Science Program and the Subcommittee on Global Change Research’s *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources* (CCSP 2008d) and *Thresholds of Climate Change in Ecosystems* (CCSP 2009b); NRC’s *America’s Climate Choices: Advancing the Science of Climate Change* (NRC 2010c); NRC’s *Climate Stabilization Targets* (NRC 2010a); and EPA’s *Climate Change Indicators in the United States* (EPA 2010c). The ecosystems addressed in this section include terrestrial ecosystems, such as forests, grasslands, shrublands, savanna, and tundra; aquatic ecosystems, such as rivers, lakes, and ponds; and freshwater wetlands, including marshes, swamps, and bogs.

Recent findings continue to indicate that terrestrial and freshwater ecosystems in the United States and around the world are experiencing rapid and observable changes. Steadily warming temperatures, rising CO_2 concentrations, and changing precipitation patterns are already leading to shifting species ranges and earlier spring migrations, as well as threatening the ability of some existing habitats to thrive. Climate change is also affecting the relative timing of species life-cycle events, referred to as "phenology," which can upset existing species interactions, dependencies, and predator-prey interactions. Terrestrial and freshwater ecosystems are also affected by wildfires, insect outbreaks, and changes in human activity such as land-use change, hydrologic modification, and pollution.

5.5.3.1.1 Phenology

Recent studies support the conclusions of earlier work indicating that the phenology of plant and animal species will continue to change in regions that experience warmer annual average temperatures and earlier spring weather. Amphibian reproductive behaviors heavily depend on temperature and rainfall patterns. One new study (Todd et al. 2011) examines the phenology of amphibians at a wetland situated in a hardwood-pine forest in South Carolina over a 30-year period (1978 to 2008). The study indicates that in recent years, several amphibian species that breed in autumn are breeding increasingly later in the year, which is consistent with an increase in local nighttime air temperature of approximately 1.2 °C (2.2 °F) during the September and February pre-breeding and breeding periods (the increase in winter nighttime temperatures allows for autumn breeding to occur later). Similarly, two amphibian species that breed in winter are breeding increasingly earlier in the year; this coincides with the increase in overnight temperature during the breeding season and an increase in rainfall during the pre-breeding and breeding seasons. Of the 10 species studied, 4 have changed their reproductive timing by a range of approximately 15 to 76 days over the 30-year period of record.

Another study of flowering patterns in a meadow system in the southern Rocky Mountains (Aldridge et al. 2011) found shifts in the timing of plant behavior. Historically, flowering in this system has occurred with one broad unimodal peak lasting most of the summer (based on three complementary peaks of the three meadow types in the system). However, recent increases in mid-summer temperatures have led to shifts in the timing of flowering within the three meadow types. The study found that there are now two peaks in flowering during the summer, characterized by a mid-summer reduction in the total number of flowers. This pattern is potentially harmful to the montane meadow system because it might not meet the continuous demand of pollinators throughout summer (in this case, hummingbirds and 13 species of bumblebees). If nectar food sources (a primary source of energy for pollinators) are not available, the lack of food can threaten population numbers.

5.5.3.1.2 Species Competitiveness and Abundance

Worldwide, ice cover on most lakes has declined in recent decades (Urban et al. 2011 citing Magnuson et al. 2000). This pattern is likely affecting the relative success of competing fish species in many areas (Urban et al. 2011). For example, one new study (Urban et al. 2011 citing Helland et al. 2011) on several coldwater fish species in Norwegian lakes indicates that recent reductions in lake ice cover, along with projected future losses in cover, could harm some species while potentially helping others. The study found that brown trout biomass is affected, sometimes positively and sometimes negatively, by changes in ice cover, but only when the Arctic char (the most widely distributed freshwater fish in the world at such a high latitude) is present. When both species are present, trout biomass decreases with each additional day of ice cover. The authors suggest that the mechanisms for this relationship are as follows: Arctic char ingest more food and grow more quickly in cold winter temperatures and during periods of darkness, outcompeting the brown trout. Thus, during periods with ice cover, Arctic char are better able to thrive than the trout. Conversely, trout outperform char when climate conditions are warmer. Changes in climate that result in shorter periods of winter weather and reduced ice cover therefore affect the relative competitiveness of these two species.

5.5.3.1.3 Ecological Tipping Points and Biodiversity

A new report by the Convention on Biological Diversity contributes to our understanding of the ecosystem-wide impacts in the event of the loss of keystone plant and animal species, the introduction of new species, and/or changes to the physical structure of the system (for example, loss of permafrost). Similar to the concept of tipping points in ocean or climate systems discussed in Section 5.3.4, *ecological tipping points* begin with initial changes in a biological system (for example, the introduction of a new predatory animal species to the system due to changes in climate that are favorable to the newly introduced species), which are then amplified by positive feedback loops that can lead to cascading effects throughout the system. The point at which the system can no longer retain stability is a threshold known as a tipping point. Changes in such situations are often long lasting and difficult to roll back; management of these conditions is often very difficult (Leadley et al 2010). Leadley et al. (2010) recently evaluated the potential tipping point mechanisms and their effects on biodiversity and ecosystem services for several ecosystems, as described in the following paragraphs.

Arctic Tundra

By the end of the century, Arctic regions are projected to experience greater warming compared to other locations around the globe, with increases projected to range from 3 ^{o}C (5 ^{o}F) to 8 ^{o}C (14 ^{o}F) under the range of possible emissions scenarios (lowest to highest, respectively), compared to conditions during the baseline used in the report (1980 to 1999). Such warming is expected to cause high loss of permafrost, which is likely to lead to the release of emissions of GHGs from tundra soils. Additionally, the change of high albedo tundra to lower-albedo boreal forest will provide a warming feedback. The lags in Earth’s responses to increased atmospheric GHGs make these changes “inevitable and irreversible over the 21st century.” The impacts for biodiversity due to changes in arctic tundra include decreases in herbaceous, bryophyte, and lichen species, and increases in boreal forests. The authors suggest that certainty and understanding of these projections are high, while the potential for adaptive mechanisms is low (adaptive mechanisms are isolated to small areas) (Leadley et al. 2010).

Mediterranean Forest

Increasing abandonment of rural areas in Mediterranean regions (due to factors unrelated to changes in climate) is likely to decrease land use for crops. Consequently, these areas are likely to see natural regeneration of forests and other native vegetation. In addition, global climate models indicate that these areas will also experience warmer temperatures and decreased precipitation over the next century, leading to more frequent drought and a greater risk of fires. The resultant increase in fire disturbances is projected to consequently encourage the growth of more shrublands, which provide a positive feedback for fire disturbances. Increases in fire-control demands will result in higher costs to the public for these services, while reducing the funds available for investment in infrastructure. Compared to forests and croplands, shrublands typically contain fewer species of plants and animals, so these changes are projected to lead to a great reduction in species diversity. Several regulating ecosystem services, such as carbon sequestration and watershed protection, will also be threatened by these shifts (Leadley et al. 2010).

Amazonian Forest

Leadley et al. (2010) suggest that two “interacting tipping points” in the Amazon could lead to widespread dieback of tropical forest. First, the large-scale change in land use from forest to managed agriculture could alter local and regional rainfall patterns, potentially initiating or exacerbating existing drought conditions; this situation could further reduce forest cover in the event of severe fire disturbance. Second, global climate models indicate that the region could experience substantial reductions in rainfall. A drier climate could result in forests permanently changing to shrubs and grasses more suited to the conditions. The region today might be close to a “forest dieback tipping point.” Because the Amazon is home to many diverse species of plants and animals, a widespread dieback would likely result in a number of previously unforeseen species extinctions. Additional ecosystem services impacts (i.e., services that ecosystems inherently provide to humans) include loss of carbon sequestration in both vegetation and soils. The understanding of the mechanisms involved and the certainty of these projections is moderate to low (Leadley et al. 2010).

Freshwater Lakes and Rivers

An increase in phosphorus and nitrogen in freshwater resources (like lakes and rivers) is often referred to as *eutrophication*. Sources for these nutrients typically include agricultural fertilizers and sewage. The effects of eutrophication include excessive growth of algae (algal blooms), which reduce dissolved oxygen in the water, causing plants, fish, and invertebrates to die. Often, as native plant and animal species die, they are replaced with invasive species, changing the basic makeup of the ecosystem. Large increases in fertilizer use and sewage outputs in Asia, Africa, and Latin America, along with decreasing precipitation and increasing water stress in some regions, are projected to result in much more widespread problems with eutrophication (Leadley et al. 2010).

Another new study reports that the fossil record indicates that previous abrupt shifts in ecological regimes were common during the Quaternary period, at least partially in response to significant changes in climate accompanying a long period of deglaciation; this historical record assists in projecting how Earth’s systems are likely to respond to change in the future. A combination of many factors (some extrinisic and some intrinsic to the system) are the likely reasons behind these abrupt shifts. Changes recorded include rapid changes in plant and animal species, and changes in the composition of entire ecological communities. While it is not possible to attribute the cause of these shifts entirely to changes in climate, the authors suggest that the “demographic processes in plant populations are quite sensitive to abrupt climate change, with initial time lags measured on the order of decades” (Williams et al. 2011 citing Ammann et al. 2000, Williams et al. 2002, and Yu 2007). Although abrupt shifts can be damaging to the overall health of populations, and some species have demonstrated an ability to migrate in the face of ambient changes, previous estimates indicate that most plants can migrate (e.g., by seed propagation) no faster than 1.0 kilometer (0.6 mile) per year (Williams et al. 2011 citing Pearson 2006).

5.5.4 Marine, Coastal, and Low-lying Areas

5.5.4.1 Recent Findings

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on marine, coastal, and low-lying areas in the United States and globally. For information on previously reported findings, *see* Section 4.5.5 (*Marine, Coastal, and Low-lying Areas*) of the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS. These findings are drawn primarily from the following major international or national scientific assessment reports: EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act* (EPA 2009e); U.S. Global Change Research Program's *Global Climate Change Impacts in the United States* (GCRP 2009); IPCC *Fourth Assessment Report* (IPCC 2007a, IPCC 2007b, IPCC 2007c); National Science and Technology Council's *Scientific Assessment of the Effects of Global Change on the United States (*National Science and Technology Council 2008); U.S. Climate Change Science Program and the Subcommittee on Global Change Research's *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity* (CCSP 2008e); Arctic Climate Impact Assessment (ACIA 2005), NRC's *Climate Stabilization Targets* (NRC 2010a); and the United Nations Environmental Programme's (UNEP) *Climate Change Science Compendium* (UNEP 2009).

These environments are particularly vulnerable to warming water temperatures, sea-level rise, melting of freshwater ice, storm events, and water acidification. Overall, new studies confirm the findings previously presented, although some newer published articles have expressed concern that sea levels might be rising faster than anticipated due to the accelerated reduction of ice sheet loss in Greenland and Antarctica that is contributing to higher sea level.

5.5.4.1.1 Anthropogenic Pressures

Climate change impacts on sea-level rise and ocean temperatures could affect large coastal populations. Roughly 200 million people worldwide live within coastal floodplains, along two million square kilometers (800,000 square miles) of land (Milne et al. 2009 citing Stern 2007). These populations are potentially at risk due to increased sea-level rise. As discussed in the MY 2014–2018 HD Final EIS, recent studies project that sea-level rise could approach or exceed 1 meter (3.3 feet) by 2100. Weiss et al. (2011) developed a new geospatial dataset based on present-day local coastal elevations, taking into account hydrological connectivity (i.e., the path that water from rising sea level will take on the surface, accounting for infrastructure such as channels and levees) and the presence of tidal wetlands landward of the shoreline. This study identifies coastlines that would be vulnerable to increases in sea level of 1 meter and 6 meters (19.8 feet), suggesting that these amounts are possible by the end of the century. This study mapped surveys of which regions of the United States would be at risk, including 20 municipalities with more than 300,000 people each, and 160 municipalities with populations between 50,000 and 300,000. These coastal municipalities have elevations at or below 6 meters (19.8 feet). This study projects a number of coastlines to be at risk, including the Gulf and southern Atlantic coasts; cities especially at risk in the U.S. include Miami, New Orleans, and Virginia Beach, because these cities have more than 90 percent of their land at or below 6 meters above sea level along the coast (Weiss et al. 2011).

Sea-surface temperature increases could also play a role in the incidence of hurricanes in the Atlantic Ocean. The National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory used two hurricane simulation models driven with the projected sea-surface temperatures and atmospheric state described in 18 World Climate Research Programme CMIP3 climate models under a moderate (A1B) emission scenario. The models project that while the absolute number of total hurricanes and tropical storms might decrease on an annual basis by the end of the twenty-first century, there would be a near doubling of the most intense hurricanes (category 4 and 5 storms with sustained winds at or greater than 131 miles per hour), compared to the 1981 to 2005 average, with the largest increase projected to occur in the western Atlantic north of 20 degrees north latitude (Bender et al. 2010). These stronger hurricanes could threaten many coastal communities that have not yet undertaken adaptation measures to protect against stronger storms.

5.5.4.1.2 Ecological Changes

As discussed in the MY 2014–2018 HD Final EIS, coral species play an integral role in the environment and act as "fish nurseries" for many different marine species. Coral reefs participate in living symbiotic relationships that are long-lived, but are very sensitive to long-term changes in temperature. Multiple species of coral, including two key species important to ecosystems, have shifted their range toward higher latitudes since the 1930s as a result of warming ocean temperatures, with some species shifting northward by up to 14 kilometers (8.4 miles) per year (Yamano et al. 2011). Recent modeling described by Periera et al. *(*2010) suggests that continued poleward shifts and greater dispersal of marine organisms will occur from rising ocean temperatures (Yamano et al. 2011).

5.5.4.1.3 Sea Level

Climate change increases global sea level through two dominant pathways: melting land-based ice caps and glaciers, and the thermal expansion of ocean waters due to increasing temperatures. A recent study by Kemp et al. (2011) on a reconstruction of sea level over the last 2,100 years along the North Carolina coast found that sea level was relatively stable from 100 BC until 950 AD. Sea levels then increased at a rate of 0.6 millimeter (0.02 inch) per year for 400 years, followed by a long stable period that lasted into the nineteenth century, with drops in sea level during the last Little Ice Age. The century-scale sea-level rise is currently at its sharpest rate of increase within the entire 2 millennia study period of reconstruction, averaging 2.1 millimeters (0.08 inch) per year off the coast of North Carolina (Kemp et al. 2011).

Studies now show that the contribution of melting from large ice sheets to global sea-level rise is larger than previously modeled (Grinsted et al. 2010 citing Hansen 2007). A 20-year study funded by the National Aeronautics and Space Administration (NASA) suggests that ice sheets in Greenland and the Antarctic are melting at an increasing pace with each passing year (Rignot et al. 2011). The increased loss of ice sheets has been directly correlated to warmer summer temperatures (Gardner et al. 2011). Average losses from ice sheets in those regions grew year over year by 21.9 billion metric tons (24.1 billion short tons) in Greenland and 14.5 billion metric tons (16.0 billion short tons) in Antarctica during 18 years of monitoring (Rignot et al. 2011). Total losses from both ice sheets averaged roughly 475 billion metric tons (534 billion short tons) of ice each year, enough to raise average global sea levels by 1.3 millimeters (0.05 inch) per year based on the added volume alone.

The NASA-funded study described above supports the findings cited in the MY 2014–2018 HD Final EIS that sea levels will rise faster than projected in the IPCC 2007 report due to the pace of ice sheet loss in Antarctica and Greenland (Rignot et al. 2011). The same study proposes that if current ice sheet melting rates continue, average total sea-level rise could reach 32 centimeters (12.6 inches) above current averages by 2050 from melting ice sheets, glacial ice caps, and thermal expansion. Another study projects changes in ice volume of all mountain glaciers and ice caps on Earth, using a surface mass balance model driven with temperature and precipitation projections from 10 World Climate Research Programme CMIP3 climate models under a moderate (A1B) emission scenario. This study suggests that glaciers could lose up to 75 percent of their present ice volume by 2100 (Radic and Hock 2011).

5.5.4.1.4 Hypoxia and Acidification

Hypoxia in ocean environments is a condition under which the dissolved oxygen level in the water is low enough to be detrimental to resident aquatic species. Recent research has found that the ability of marine organisms to survive in hypoxic conditions is further strained by warming ocean temperatures. Marine benthic organisms have been shown to have significantly shortened survival times when subjected to warmer hypoxic conditions, as the necessary dissolved oxygen threshold for survival increases with temperature (Vaquer-Sunyer and Duarte 2011).

Under projected global ocean warming, the vulnerability of marine organisms to hypoxic conditions will be increased and regions of hypoxia will continue to expand to a larger number of coastal ecosystems (Vaquer-Sunyer and Duarte 2011). Temperature increases are believed to be correlated directly to the expansion of hypoxic zones, because they affect a variety of complex mechanisms such as increasing the stratification of marine waters (Vaquer-Sunyer and Duarte 2011 citing Conley et al. 2007). Ocean acidification through the increased creation of carbonic acid (caused by increasing concentrations of CO_2 in the atmosphere) will reduce the ability of marine species to perform calcification, part of the process for making shells and creating coral habitats (Periera et al. 2010). Higher mortality rates for marine organisms are expected due to the continuing acidification of oceans (Maclean and Wilson 2011 citing Orr et al. 2005).

5.5.4.1.5 Salinity

Ocean salinity levels can be affected by freshwater additions, ocean evaporation, and the freezing or thawing of ice caps and glaciers. Marine organisms are adapted to specific levels of ocean salinity and often become stressed by changing salinity levels. Additionally, changing salinity levels of the ocean affect the density of water, which in turn, impact factors such as the availability of local drinking water and, potentially, global ocean circulation patterns. Durack and Wijffels (2010) investigated the decreased average salinity from 1950 to 2008 across global ocean systems. Although the globally averaged salinity change is small, changes in regional basins have been significant. Evaporation-dominated subtropical regions are exhibiting definite salinity increases, while regions dominated by precipitation are undergoing increasing freshening in response to intensification of the hydrological cycle. These effects are amplified in regions that are experiencing increasing precipitation or evaporation. New findings through surface water analyses of the Atlantic Ocean show increased salinity, while the Pacific Ocean demonstrates decreased salinity, and the Indian Ocean has observed near-neutral changes (Durack and Wijffels 2010). However, these are general trends and vary somewhat, both across the large bodies of water and below thermocline levels. Changes in salinity are likely to affect ocean density and structure in the future; they will also likely influence ocean circulations, especially at higher latitudes where salinity is a more active variable.

5.5.4.1.6 Productivity

Satellite observations of ocean chlorophyll indicate that global ocean annual primary production has declined by more than 6 percent since the early 1980s, with almost 70 percent of this decline occurring in the high latitudes (Brander 2010 citing Gregg et al. 2003). Chlorophyll is a constituent of photosynthetic organisms such as algae, and is an indicator of ecosystem productivity that is visible from satellite observations of Earth's oceans. The low latitudes generally experienced an increase in ocean primary productivity. In the northern high latitudes, these reductions correspond in part to increases in sea surface temperature.

In the past, ocean productivity has generally adjusted to natural variations in ocean climate. However, present climatic trends are expected to continue outside the bounds of previous variability at a much faster rate. Three factors are likely to affect projections of ocean productivity in response to climate change: warming temperatures, light (as described by ice cover, cloudiness, and mixed layer thickness), and altered nutrient supplies, with warming temperatures potentially the largest single factor affecting productivity (Brander 2010).

5.5.4.2 Adaptation

Projected impacts from climate change will likely require some level of adaptation from affected marine, coastal, and low-lying regions. Recent information on climate change adaptation supports previous findings. Adaptation for sea-level rise falls mostly into three major categories: retreat, accommodate, and protect (Nicholls 2011). Retreating allows the impacts of sea-level rise to occur unobstructed, while inhabitants pull back from inundated coastlines. Accommodation is the strategy of adjusting the use of coastal zones where impacts are likely (e.g., through constructing raised homes and implementing resilience measures such as early warning systems and increased insurance). Protection is the creation of barriers against sea intrusion through the use of replenished beaches and seawalls.

5.5.5 Food, Fiber, and Forest Products

5.5.5.1 Recent Findings

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on food, fiber, and forest product resources in the United States and globally. For information on previously reported findings, *see* Section 4.5.6 (*Food, Fiber, and Forest Products*) of the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS. These findings are drawn primarily from the following major international or national scientific assessment reports: IPCC's *Fourth Assessment Report* (IPCC 2007a, IPCC 2007b, IPCC 2007c); EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act* (EPA 2009e); U.S. Climate Change Science Program and the Subcommittee on Global Change Research's *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity* (CCSP 2008e); U.S. Global Change Research Program's *Global Climate Change Impacts in the United States* (GCRP 2009); NRC's *Climate Stabilization Targets* (NRC 2010a); and EPA's *Climate Change Indicators in the United States* (EPA 2010c).

Overall, new studies confirm the previous research documenting and predicting changes in forest health and composition, agricultural yields, and fishery productivity. However, there is increasing evidence that climate change is already affecting forestry, agriculture, and fisheries across the world. Recent research has focused on detailing impacts to specific regions and systems to provide better information for adaptation.

5.5.5.1.1 Forests

Reports continue to focus on attributing drought-induced tree mortality events, regional forest dieoffs, and vegetation shifts to climatic drivers (Carnicer et al. 2011, Sturrock et al. 2011). For example, there is strong evidence that climate change is contributing to severe droughts in the Northern Hemisphere, causing regional tree dieoffs (Carnicer et al. 2011). While changes in forest composition and structure have been observed for decades, recent studies attempt to distinguish the relative importance of climatic drivers to other factors such as land-use change. For example, a recent study of changes in forest composition in Panama since the 1980s found a correlation between climate changes and shifts toward tree species with a greater drought tolerance, although it did not establish causality, given that other factors such as El Niño could also be responsible for the increased occurrence of drought (Feeley et al. 2011).

Recent studies have also found changes in forest structure and composition across the world, though they have not attempted to distinguish climate change from other causes. For example, long-term studies have reported dramatic changes in the dynamics of tropical forests over the past few decades (Feeley et al. 2011). Forest composition has been changing in China as well, with species such as *Larix gmelinii (*a species of larch native to eastern Siberia, and adjacent northeastern Mongolia, northeastern China, and North Korea) and *Picea jazoensis* (Yezo spruce) shifting northward in recent decades (Sturrock et al. 2011). Recent warming has already resulted in earlier flowering and vegetative bud burst in some forest trees, a trend that is expected to continue (Chmura et al. 2011). Another study found that Iberian forests are experiencing long-term effects due to severe climate-change-related droughts. There have also been trends toward increasing defoliation and mortality in southern European forests (Carnicer et al. 2011).

Recent work on projected climate impacts on forests focuses on the interaction of climate change with existing stressors. For example, climate change is projected to increase the frequency and severity of forest fires in areas such as the North American boreal forest (Krawchuk and Cumming 2011). A recent modeling study using the Canadian Regional Climate model under a moderately high (A2) emission scenario found that forest harvesting could be reducing the severity and frequency of wildfires. However, the combination of climate change and harvesting could permanently change the structure of boreal forest and negatively affect species and ecological communities that rely on that forest (e.g., songbirds). Overall, the study projected a 39 percent increase in fire initiation and a 47 percent increase in area burned for western Canadian boreal forest from 2080 to 2089, compared with a baseline period of 1975 to 1985 (Krawchuk and Cumming 2011).

5.5.5.1.2 Agriculture and Croplands

At the time the MY 2014–2018 HD Final EIS was completed, quantifying the impacts of climate change on food systems was challenging due to the complexity of interactions between crops and climatic drivers. Recent work in this area has focused on understanding the geographic distribution of yield losses and determining viable adaptation options.

The impact of climate change on crop yields will vary by region and by crop. For example, climate change could have primarily positive impacts on production and range of favorable crop species in northern Europe but negative impacts in southern areas such as the Mediterranean basin (Moriondo et al. 2011). Moriondo et al. (2011) applied the end-of-century projections of mean and extreme temperatures from the Regional Circulation Model under the low (B2) and moderately high (A2) emission scenarios to the crop model, and found that by the end of the century the growing season would shorten, there would be a general advancement of the main phenological stages, and there would be an increase in heat stress (compared to 1961 to 1990 baseline conditions). Sunflowers grown in southern Mediterranean countries were projected to be adversely affected by heat stress at anthesis (when a flower is open and fully functional), and by drought during the growing cycle. Conversely, the winter wheat crop was projected to sustain lower frequency of heat stress. Drought is projected to increase winter wheat yield by the end of the century compared to baseline conditions.

Another recent study used a modeling approach to isolate the impact of increasing temperatures on wheat yield. The study found that observed variations in average growing season temperatures of plus or minus 2 °C (3.6 °F) in the main wheat growing regions of Australia could cause reductions in grain production of up to 50 percent. The study also found that each additional day over 34 °C (93 °F) during sensitive crop growth periods resulted in a 5 percent grain yield decrease (Asseng et al. 2011).

Recent studies have corroborated the finding reported in the MY 2014–2018 HD Final EIS that Sub-Saharan Africa will likely be particularly vulnerable to climate change impacts on agriculture. In Sub-Saharan Africa, historical temperature increase and rainfall decrease have led to a production shortage since the 1970s. By mid century, 16 recent studies project changes in crop yield from minus 50 percent to plus 90 percent, with a median value of minus 11 percent (Roudier et al. 2011). Results indicate that impacts on crop yield in this region are most severe under intense warming scenarios, but rainfall can mitigate some of the projected damages (Roudier et al. 2011).

5.5.5.1.3 Fisheries

Changes in marine biodiversity, such as reductions in the abundance of large predatory fish and widespread mortality of reef structures and associated fish communities, are well documented. It is difficult to determine how global changes such as overfishing, coastal eutrophication, and climate change have each contributed to these trends (Rice and Garcia 2011). However, recent studies on climate change impacts on fisheries report that fishery production, spatial distribution, and phenology are at significant risk from climate change. For example, Overholtz et al. (2011) documented the sensitivity of Atlantic mackerel, which are found from Cape Hatteras to Newfoundland, to changes in temperature. The study found that over the past 40 years (1968 to 2008), the distribution of mackerel has shifted approximately 250 kilometers (155 miles) to the north and east. These changes are correlated with interannual temperature variability and gradual warming.

Researchers are currently developing models to project patterns of marine biodiversity under future climate change scenarios. Initial studies project that climate change will continue to alter community ranges and species biomass (Rice and Garcia 2011). For example, future changes in species distributions and maximum catch potential in the Northeast Atlantic will depend on changes in oxygen content, acidity, and phytoplankton community structure. A recently developed model, NOAA GFDL ESM2.1, projects under a moderate (A1B) emission scenario that the distributions of 120 fish and invertebrate species in the Northeast Atlantic would shift northward at an average rate of roughly 46 to 52 kilometers (29 to 32 miles) per decade and deeper at an average rate of roughly 5 meters (16 feet) per decade, with the higher values of the range allowing for high physiological sensitivity to ocean acidification. Overall, the study found that the projected maximum catch potential in 2050 would decline substantially (Cheung et al. 2011). Despite recent advances in research, it is difficult to determine whether ocean primary productivity will rise or fall as a result of ocean warming, ocean acidification, and other global changes (Murawski 2011).

5.5.5.1.4 Disease, Pathogens, Insects, and Weed Species

Confirming findings reported in the MY 2012–2016 CAFE standards Final EIS, a recent study concludes that the last few decades have seen significant increases in large-scale decline and disease outbreaks in plant species, and this pattern is expected to continue globally (Grulke 2011). Climate variability and change can play a role in these outbreaks. For example, the hot and dry conditions of 2004 contributed to tree canker outbreaks in Alaska (cankers are localized dead areas on a tree) (Grulke 2011). The impact of climate change on pathogens will vary depending on the specific relationship between the host, the pathogen, and the environment.

Recent research focuses on integrating analysis of pathogen dynamics into studies of how climate change impacts ecosystems and agricultural systems. For example, Olofsson et al. (2011) recently investigated how plant disease will mediate the response of ecosystems to climate change by studying tundra grass growth under increased snow-cover conditions in Sweden. They found that although the changing climate conditions favored increased biomass growth, the emergence of a parasite decreased growth. Another recent study found that projected changes in precipitation can dramatically influence the dynamics of forest pathogen species. A warmer and wetter future will likely promote pest impacts from species such as *Phytophthora* root rot and sudden oak death. Conversely, a warmer, drier future would promote increased impacts from pathogens such as *Armillaria* root disease (Sturrock et al. 2011).

5.5.5.2 Adaptation

Maintaining the complexity of forest structure and composition is an adaptation option that has garnered widespread political and scientific acceptance. However, because there could be tradeoffs between carbon storage and forest complexity (e.g., species diversity), it will be necessary to balance mitigation and adaptation goals (D'Amato et al. 2011). Additional adaptation options include assisting species migrations and managing forest composition and density to reduce drought stress and risk of fire and insect disturbance. In addition, post-disturbance periods could provide opportunities for adaptively altering species composition (Chmura et al. 2011).

In the agriculture sector, there are many adaptation options that could offset yield decreases. For example, one recent modeling study investigated the potential impacts of climate change on crops by using a global crop model driven by annual mean temperature and precipitation data from two climate models used by the IPCC Fourth Assessment Report under moderate (A1B) and low (B1) emission scenarios. This study found that while projected climate changes will decrease global crop yields by 2050 if planting and harvesting dates remain unchanged, adapting those dates and changing cultivar choices can avoid 7 to 18 percent of global losses (Deryng et al. 2011). In addition, using longer-season cultivars and cultivars with increased resilience to extreme temperatures and droughts could offset projected yield decreases (Turner et al. 2011). In some regions, farmers have already begun adapting to climate change. For example, in areas of Australia where farmers traditionally have grown oats, reduced precipitation and soil waterlogging has allowed them to begin producing wheat (Turner et al. 2011).

5.5.6 Industries, Settlements, and Societies

5.5.6.1 Recent Findings

This section provides an overview of recent findings regarding observed and projected impacts of climate change on industries, settlements, and societies in the United States and globally. For information on previously reported findings, *see* Section 4.5.7 (*Industries, Settlements, and Societies*) of the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS. These findings are drawn primarily from the following major international or national scientific assessment reports: IPCC's *Fourth Assessment Report* (IPCC 2007a, IPCC 2007b, IPCC 2007c); EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act* (EPA 2009e); U.S. Climate Change Science Program and the Subcommittee on Global Change Research's *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I* (CCSP 2008a); Transportation Research Board Special Report 's *Potential Impacts of Climate Change on U.S. Transportation* (Transportation Research Board 2008); NRC's *Climate Stabilization Targets* (NRC 2010a); and EPA's *Climate Change Indicators* (EPA 2010c).

Two literature synthesis reports, Gosling et al. (2011) and Hunt and Watkiss (2011), published after the the issuance of the MY 2014–2018 HD Final EIS in June 2011, discuss projected climate change impacts in the industries, settlements, and societies sector. Gosling et al. (2011) state that literature published since the IPCC Fourth Assessment Report confirms the general trends from previous research findings pertaining to this sector. Hunt and Watkiss (2011) focus on projected impacts to cities and reaffirm the overall projected impacts of climate change on the industries, settlements, and societies sector. Overall, these new studies confirm previous findings with several minor exceptions noted in the relevant sections below. One new study also suggests an impact not discussed in the MY 2012–2016 CAFE standards Final EIS or the MY 2014–2018 HD Final EIS: the potential direct damage to concrete infrastructure due to higher concentrations of CO_2 (Stewart et al. 2011). New research for this sector is trending toward an emphasis on city-specific studies (Gosling et al. 2011, Hunt and Watkiss 2011) that provide illustrative examples of potential climate change impacts to communities. Notably, city-specific factors and study methodologies make the results difficult to compare or transfer to other cities (Hallegatte and Corfee-Morlot 2011).

5.5.6.1.1 Industries

Established research, outlined in the 2014–2018 HD Final EIS, demonstrates that industries, including manufacturing, transportation, energy supply and demand, mining, and construction, are vulnerable to climate change, most notably in the form of extreme weather events, changes in precipitation, and heat stress.

Recent research by Pearce et al. (2011) explores the vulnerability of the Canadian mining industry to climate change. Pearce et al. found that projected impacts to mining industries, including extreme weather events and associated structural weakening, and impacts to transportation systems, will have rippling effects throughout the economy, because mining is often a central industry. The study analyzed five in-depth case studies of Canadian mines, representing the range of mines over the industry, and found that all are already experiencing climate-related impacts, such as a reduction in ice roads for transporting goods to and from the mines, worsened dust emissions from quarries due to warmer temperatures, and limited water supplies. The study also identifies a new vulnerability of the mining industry – higher temperatures and diminished permafrost represent a large risk to the structural integrity of post-operational and abandoned mines.

5.5.6.1.2 Services and the Economy

Projected impacts of climate change to services and the economy include impacts to the tourism and insurance industries due to changing weather norms and shifts in extreme events. Climate change also could affect the economy through impacts, direct or indirect, to trade, retail, and commercial services.

Any projected climate change impacts to cities and human settlements, as discussed throughout this section, are likely to have economic repercussions, because cities are concentrated areas of wealth and economic activity (Hallegatte et al. 2011). The potential effects of climate change on urban economies include the impacts of changes in tourism, decreases in worker productivity due to potential health problems, and impacts to long-term economic development (Hallegatte et al. 2011).

Climate and tourism are closely linked, but the economic consequences of climate change on tourism will vary by location. Climate change is projected to have an overall effect of redistributing tourism income globally, regardless of whether there is a net change in the size of the tourism industry (Hernandez and Ryan 2011).

5.5.6.1.3 Utilities and Infrastructure

Utilities and infrastructure are projected to experience damage as a result of changing temperature, precipitation patterns, extreme weather events, storm surges, and sea-level rise. Stewart et al. (2011) introduce a projected vulnerability of infrastructure to climate change not previously discussed in the MY 2014–2018 HD Final EIS. Their study focused on Australian infrastructure using an Australian model, OZ-Clim, driven with nine World Climate Research Programme CMIP3 climate model projections, and found that concrete infrastructure is susceptible to corrosion directly from increased atmospheric concentrations of CO_2, notwithstanding projected physical vulnerabilities to storm events and sea-level rise. The study estimates that climate change would increase concrete corrosion risks by 40 to 460 percent over a range of four emission scenarios for some regions in Australia.

Climate change is also projected to affect transportation systems, which, as a whole, are vulnerable to the impacts of climate change in many ways. These impacts are discussed in the MY 2014–2018 HD Final EIS, and include physical damage from weather events, increased safety concerns, and temperature effects on material types. Meyer and Weigel (2011) reiterate many of these concerns, including risks to infrastructural stability due to changing soil saturation, potential changes in necessary materials selection, and the need to consider projected precipitation changes in drainage system designs. Walker et al. (2011) have delved into the specific projected impacts of climate change in Portland, Oregon, which include a projected 10 percent increase in precipitation, a seasonal shift from summer to winter precipitation, an increase in precipitation falling as rain rather than snow, reduced snowpack in nearby mountain rainges, and an overall temperature increase of 2 to 3 °C (3.6 to 5.4 °F). All of these projected changes could affect ground transportation systems by impacting operations and maintenance practices.

As discussed in the MY 2014–2018 HD Final EIS, climate change has the potential to affect energy supplies, including some forms of renewable energy. Recent studies (Cai et al. 2011, Doppelt et al. 2011) reiterate this as an issue of concern. Hydropower resources are one renewable energy source that could be affected by climate change. While earlier research findings cited in the MY 2014–2018 HD Final EIS found that certain areas could experience increases in hydropower resources due to increased precipitation, more recent studies show that hydropower resources could be diminished in some areas due, for example, to decreases in snowpack (Doppelt et al. 2011) or increased evaporation from reservoirs (Cai et al. 2011 citing Gleick 1992). These latest reports reiterate the idea repeated throughout the literature that projected climate impacts, particularly on the scale of human settlements, depend on local conditions.

One recent study also examines the projected impact of climate change on wind energy resources. Earlier research cited in the MY 2014–2018 HD Final EIS found that wind energy resources are not expected to change significantly in northern Europe. The latest research reaches similar conclusions with respect to the United States. Pryor and Barthelmie (2011) found that mid-century projected changes to wind resources as a result of climate change will not be outside the range of current wind variability, particularly in the areas of the United States with the greatest installed wind energy capacity. The study analyzed climate projections for the moderately high (A2) emission scenario from the North American Regional Climate Change Assessment Program regional climate model, nested within three atmosphere-ocean general circulation models, CGCM3, HRM3, and HadCM3, and one observationally derived dataset, the National Centers for Environmental Protection-U.S. Department of Energy reanalysis.

In addition, water utilities could be vulnerable to climate change. In a study projecting change in water demand in the Puget Sound region of Washington State, Polebitski et al. (2011) found that projected climate change is likely to influence water demand and stress on public utilities. The study incorporates downscaled projections from a large climate model ensemble under a moderately high (A2) emission scenario, and finds that over the next 25 to 30 years these impacts will be counteracted by improvements in water conservation; however, Polebitski et al. state that over time, temperature-driven increases in demand could come to outweigh other factors and create stress on water resources.

5.5.6.1.4 Human Settlements

Human settlements are primarily vulnerable to flood risks from sea-level rise, physical damage from extreme events or precipitation, and impacts to water supplies from sea-level rise and changes in precipitation patterns.

Vulnerability of human settlements to climate change varies by city and depends on factors such as exposure to extreme events, local topography, building norms, the city's socioeconomic structure, and cultural aspects of the population (Hallegatte and Corfee-Morlot 2011). Hunt and Watkiss (2011) reviewed the literature on climate change impacts in cities and found that research has focused on sea-level rise, health impacts, and impacts to water resources, with less research on climate impacts to energy, transportation, and built infrastructure. In addition, research has focused predominately on coastal cities, leaving a research gap on the projected impacts of climate change in cities across the range of geographic locations (Hunt and Watkiss 2011).

One recent study on climate change impacts to coastal cities projected that by 2070, 150 million people globally will be exposed to 100-year flood risks (i.e., a flood that has a 1 percent chance of occurring within a given year), or three times the number of people exposed at present (Hanson et al. 2011). The projection accounted for population growth, economic growth, natural and potentially human-induced land subsidence or uplift (i.e., descending or rising elevation of land), and a homogenous global sea-level rise of 0.5 meters (1.6 feet) above current levels, which is in the upper range of IPCC sea-level projections (now considered conservative). The study projects that assets exposed to sea-level rise could increase tenfold by 2070, and that Asia will be the region with the most exposed population and assets. Two U.S. cities, Miami and New York, are in the top 20 cities in terms of population exposed to coastal flooding (Hanson et al. 2011). Four U.S. cities – Miami, New York, New Orleans, and Virginia Beach – are projected to be among the top 20 cities worldwide with the highest value of exposed assets (Hanson et al. 2011).

Recent research has also focused on projected water shortages due to climate change in addition to coastal flood risks. Arnell et al. (2011) projected that unmitigated climate change resulting in a 4 °C (7.2 °F) increase in global mean temperatures could lead to increased water shortages for between 6 and 22 percent of the global population by 2100. The study used the IMAGE integrated assessment model, accounting for projections of population, economic growth, energy and food production, land use change, GHG emissions, and climate.

5.5.6.1.5 Social Issues

Climate change is projected to have social impacts, including increased risks to vulnerable populations and cultural resources. These risks include heat waves, food insecurity, disrupted sanitation systems, and physical damage to cultural resources, and are expected to disproportionately impact the poor. However, a recent paper tempers some projections of the impacts of climate change on global poverty levels. Skoufias et al. (2011) performed a literature review of the projected impacts of climate change on poverty and found that, overall, previous studies are likely to have overestimated the impact that climate change could have on poverty. The authors note that climate change is indeed expected to slow the pace of global poverty reduction, but it is not likely to reverse declines in poverty achieved by continued economic growth. However, climate change impacts on poverty are not likely to be distributed evenly, and could affect Africa, South Asia, and other developing regions of the world more severely, along with poorer households in general (Skoufias et al. 2011). *See* Section 7.6 for a more complete discussion of the environmental justice issues associated with the proposed MY 2017–2025 CAFE standards.

5.5.6.1.6 National Security

Climate change is also projected to have implications for national security, as discussed in Sections 4.5.7.2 and 5.5 of the MY 2014–2018 HD Final EIS.

This section draws heavily from national security reports, as peer-reviewed studies are unavailable. These reports represent a collection of security assessments based on congressional testimonies and assessments from military advisory boards and councils on foreign relations.

Climate change has profound implications for America’s national security both domestically and abroad. Sea-level rise, storm surges, extreme weather events, and changes in temperature and precipitation patterns all pose serious threats to global stability. Regions in Asia, Africa, and the Middle East with marginal living standards will be particularly vulnerable as economic and environmental conditions worsen (NIC 2008, CNA 2007). Other examples of potential destabilizing conditions are water scarcity in the Middle East and flooding due to sea level rise in Bangladesh (Stevenson et al. 2010). The national security impacts to the United States will be primarily indirect, as climate change impacts will exacerbate existing problems in other countries and increase the risk of domestic instability and intra-state conflict (Fingar 2008, NIC 2008). Further, climate change acts as a threat multiplier[65] for instability in volatile regions of the world (Campbell et al. 2007, DOD 2010, NIC 2008, CNA 2007).

Areas of conflict driven by climate change that might impact U.S. and international security include the following:

- Increased conflict over resources, stemming from changes in agricultural production and freshwater availability (Brown and Crawford 2009, CNA 2007, ECEC 2008, Pew Center on Global Climate Change 2009)
- Risk of economic damage to coastal cities and critical infrastructure from sea-level rise and an increase in natural disasters (CNA 2007, Pew Center on Global Climate Change 2009, Busby 2007)
- Loss of territory and border disputes resulting from sea-level rise
- Environmentally induced migration from loss of coastal land, desertification, and a decreased availability of resources due to climate change (Pew Center on Global Climate Change 2009, ECEC 2008)
- Potential for tension and instability over energy supplies (CNA 2007, ECEC 2008)
- Increasing pressure on international governance, stemming from the potential resentment of those impacted by climate change towards those considered responsible for climate change (ECEC 2008)

These areas of conflict could add political and social tension, as well as an economic burden, to the United States and other stable countries, for example, if such countries were to accept large immigrant and refugee populations (CNA 2007, DOD 2010, ECEC 2008, Busby 2007). In addition, the U.S. military could become overextended as it responds to extreme weather events and natural disasters, along with current or future national security threats (CNA 2007, Pew Center on Global Climate Change 2009, DOD 2010, Busby 2007).

Potential resource-based conflicts overseas could result in impacts in the United States, such as increasing demand for foreign aid, and therefore reducing capacity to respond to domestic natural disasters. Conflicts over resources, particularly food and water, have been a major factor in historical episodes of warfare and violence (McNeely 2011). Projected impacts of climate change on crop productivity and on water resources, as discussed above, are therefore likely to result in future conflicts, particularly in developing areas where the availability of natural resources is already limited (McNeely 2011). As a result of the risks described above, the National Intelligence Council has expressed increasing concern regarding the geopolitical and national security consequences of climate change (NIC 2008).

5.5.6.2 Adaptation

Much of the recent literature on climate change and the industries, settlements, and societies sector has focused on ways that human settlements can adapt to the projected impacts of climate change (Cook and Dowlatabadi 2011, Doppelt et al. 2011, Hallegatte and Corfee-Morlot 2011, Hernandez and Ryan 2011, Hunt and Watkiss 2011, Kunreuther et al. 2011, Meyer and Weigel 2011, Pearce et al. 2011, Rosenzweig et al. 2011, Winn et al. 2011). Adaptation to the projected impacts of climate change has also been identified as a need by the Obama Administration, through EO 13514. Due to this order, CEQ has released guidance for Federal

[65] "Threat multiplier" refers to an action that further intensifies the instability of a system that poses a security concern.

agencies on how to implement climate change adaptation planning (CEQ 2011). Adaptation efforts in the United States are also underway at the state level, such as in California, Maryland, North Carolina, New Hampshire, Massachusetts, Oregon, and Virginia, and at the local level, such as in New York City, Miami-Dade County, Florida, and King County, Washington.

In general, settlement-level adaptation efforts to date have focused on vulnerability assessments to identify projected climate impacts and vulnerabilities at the local level and incorporation of adaptation concepts into ongoing planning efforts (Hallegate and Corfee-Morlot 2011, Hunt and Watkiss 2011). Adaptation efforts to date have also primarily focused on coastal areas and impacts such as sea-level rise and storm surge (Hunt and Watkiss 2011). New York City, for example, has developed a risk management approach for adaptation planning and is at the forefront of city climate adaptation efforts. The city has begun to implement some adaptation measures, such as raising the elevation of pumps and electrical equipment at one of the city's wastewater treatment plants (Hunt and Watkiss 2011, Rosenzweig et al. 2011).

In addition to occurring at the city or government scale, adaptation can also occur for specific businesses or industries. Winn et al. (2011) propose a new framework for businesses to think about climate change as a "massive discontinuous change" in the context of organization science. The tourism and insurance sectors are also working to develop not just adaptation measures, but also processes for prioritizing and designing them (Cook and Dowlatabadi 2011, Hernandez and Ryan 2011).

5.5.7 Human Health

5.5.7.1 Recent Findings

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on the human health sector in the United States and globally. For information on previously reported findings, *see* Section 4.5.8 (*Human Health*) of the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS. These findings are drawn primarily from the following major international or national scientific assessment reports: U.S. Climate Change Science Program and the Subcommittee on Global Change Research's *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems* (CCSP 2008f); IPCC *Fourth Assessment Report* (IPCC 2007a, IPCC 2007b, IPCC 2007c); EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act* (EPA 2009e); Harvard Medical School's *Climate Change Futures: Health, Ecological and Economic Dimensions* (Epstein et al. 2006); NRC's *America's Climate Choices: Advancing the Science of Climate Change* (NRC 2010c); NRC's *Climate Stabilization Targets* (NRC 2010a); and National Institute of Environmental Health Sciences' *Human Health Perspective on Climate Change* (Portier et al. 2010). Overall, new studies confirm the previous research documenting and predicting changes in human health.

5.5.7.1.1 Heat and Cold Events

Previous research cited in the MY 2014–2018 HD Final EIS found that the number of hot days, hot nights, and heat waves has increased, contributing to human morbidity and mortality directly through heat stress and indirectly though a heightened risk of forest fires, reduced air quality, and increased stress on the electrical grid causing brown- or blackouts. Cold days, cold nights, and frost days were found to be less common, generally producing beneficial health effects. Recent research reiterates these impacts.

Heat-related mortality and morbidity is a greater issue for cities than for rural areas, due to the urban heat island effect, in which temperatures in cities increase significantly faster compared to rural areas (Harlan and Ruddell 2011). A recent study estimated future heat-related mortality due to climate change compared to a 1961 to 1990 baseline rate using city-specific models for London, Lisbon, and Budapest, based on projections of temperature across 21 global climate models (GCMs) used in the IPCC Fourth Assessment Report under a moderate (A1B) emission scenario. The study found that climate change could have a minor impact on heat-related mortality in the 2030s, but by the 2080s, the death rate attributable to increased heat events would rise to the order of 2 to 6 per 100,000 people in London compared to a baseline of approximately 2 per 100,000 people, 4 to 50 per 100,000 people in Lisbon compared to a baseline of approximately 5 per 100,000 people, and 10 to 24 per 100,000 people in Budapest compared to a baseline of approximately 6 per 100,000 people (Gosling and Lowe 2011).

Although climate change is expected to bring about a rise in average temperatures, it is also anticipated to increase the intensity of winter storms in some places, potentially leading to an increase in cold-related mortality and morbidity. Skin exposure to cold weather can cause respiratory illness and infectious diseases such as pneumonia and influenza. In addition, older adults are generally more vulnerable to health effects from exposure to winter storms and other cold-weather events (Conlon et al. 2011).

5.5.7.1.2 Aeroallergens

As discussed in the MY 2014–2018 HD Final EIS, the state of the science continues to support the conclusion that pollen counts in North America have increased significantly in recent years, and the spring season is generally longer with the rise in temperatures, prolonging the allergy season (Friel et al. 2010 citing Food Agric. Organ. 2006; Ford et al. 2006; Frank et al. 2006).

Potential increases in allergens under a changing climate could increase respiratory health risks, particularly for children. Recent research has projected increases in weed pollen and grass pollen under various climate change simulations; these allergens are known to exacerbate children's asthma and cause hospitalizations (Sheffield and Landrigan 2011 citing Heguy et al. 2008; Schmier and Ebi 2009; Ziska et al. 2008).

5.5.7.1.3 Water- and Food-Borne Disease

Climate change is also projected to affect the rates of water- and food-borne diseases. Currently, food-borne diseases cause an estimated 5,000 deaths, 325,000 hospitalizations, and 76 million illnesses annually in the United States (Ge et al. 2011 citing Mead et al. 1999). A new study tested how climate change can affect the spread of *Salmonella*. Both extended dryness and heavy rain were tested, and the authors found that these conditions facilitated the transfer of *Salmonella typhimurium* into the edible portions of lettuce and green onion when *Salmonella* was present in the soil. If climate change were to cause excessive drought or heavy rain, it could increase the risk of disease outbreaks (Ge et al. 2011).

Climate change is also expected to significantly increase the incidence of diarrhea in some countries. A recent study investigates how six regions in the tropics and subtropics, including South America, North Africa, the Middle East, equatorial Africa, southern Africa, and Southeast Asia, all of which have high incidence of dehydration and diarrhea, could experience increases in diarrhea incidence as average temperatures rise. This study estimates an average temperature increase of 4 °C (7.2 °F) over land in the study area by the end of the century, compared to a 1961 to 1990 baseline, based on an ensemble average of 19 climate models using a moderate (A1B) emission scenario. A relatively simple linear-regression relationship was developed between diarrhea incidence and temperature increase based on the results of five independent studies. Applying this relationship, the projected mean increase in the relative risk of contracting diarrhea across the six study regions is 8 to 11 percent in the period 2010 to 2039, 15 to 20 percent in the period 2040 to 2069, and 22 to 29 percent in the period 2070 to 2099 (Kolstad and Johansson 2011).

5.5.7.1.4 Vector-Borne Disease

Vector-borne diseases are spread from one host to another through vectors, which are the transmitters of disease-carrying organisms. As discussed in the MY 2014–2018 HD Final EIS, there is significant evidence that climate change will affect vector-borne diseases such as malaria, cholera, dengue, and plague, but it is difficult to predict these impacts at local scales. For example, projecting the potential spread of mosquito-borne pathogens requires weighing conflicting responses to changes in temperature by mosquitoes. In areas with cooler average summertime temperatures (20 °C [68 °F]), a temperature increase can increase biting rates, parasite replication within mosquitoes, and mosquito development, but it can also increase mosquito mortality. The net effect could either increase or decrease the spread of vector-borne diseases, making it challenging to predict an end result (Rohr et al. 2011).

Another study found a strong relationship among Gross Domestic Product (GDP) per capita, climate change, and the risk of malaria. Socioeconomic development and public health systems have signficantly reduced the incidence of malaria in many countries, although these impacts are generally not included in studies projecting the transmission of malaria. The study uses a logistic regression model of temperature, precipitation, and GDP per capita to project vulnerable regions in 2030 and 2050 under a moderate (A1B) emission scenario. By 2050, approximately 5.2 billion people are projected to be at risk of contracting malaria if only climate change impacts are considered, 1.95 billion people are at risk if climate change impacts and GDP per capita are considered, and 1.74 billion are at risk if only GDP per capita is considered, compared to an estimated 2.3 billion people who were at risk of malaria in 1994 (Beguin et al. 2011).

In China, the transmission and risk area of Schistosomiasis, an infectious disease transmitted by parasitic worms, could be affected by rising temperatures. The study compared the temperature thresholds for both the development of the host, a type of snail, and the development of the disease itself to the projected temperature increase in China in 2030 of 0.9 °C (1.6 °F) and 2050 of 1.6 °C (2.9 °F). The study projected that this disease could expand its geographical range by 783,883 square kilometers (approximately 303,000 square miles), covering 8.1 percent of China’s surface area by 2050 (Kan et al. 2011 citing Zhou et al. 2008).

5.5.7.1.5 Skin Cancer

Climate change is expected to alter temperature, precipitation, and cloud cover, which can alter sun exposure behavior and change the risk of ultraviolet (UV) ray-related health outcomes. In addition, possible increases in the use of pesticides and herbicides to counteract projected increases in pests, diseases, and weeds in new areas could increase the risk of human exposure and health effects, including cancer (Friel et al. 2011).

Globally, there has been an increase in cases of skin cancer over the past several decades, due in part to increased exposure to UV-B radiation caused by factors such as lifestyle changes and stratospheric ozone depletion. Studies suggest that higher temperatures contribute to the development of skin carcinoma, and one new study estimates that a long-term temperature increase of 2 °C (3.6 °F) could raise the carcinogenesis effects of UV radiation by 10 percent (Andersen 2011 citing van der Leun and de Gruijl 2002).

5.5.7.1.6 Indirect Impacts on Health

As discussed in the MY 2014–2018 HD Final EIS, some of the indirect impacts of climate change on health include water scarcity, food security, and psychological impacts. A recent study estimates that cereal grain yields in South Asia will decline by 10 to 20 percent by the end of the twenty-first century due to climate change (Friel et al 2011 citing Ingram et al 2008). Overall, the potential effects of climate change on food yield, water, and fuel costs will likely raise food prices, and in turn leave some people only able to purchase energy-dense, highly processed foods rather than healthful, more expensive food, therefore increasing cases of malnutrition, obesity, and diabetes (Friel et al. 2011).

The impacts of climate change on food and water security will be particularly burdensome on children, who are more susceptible to malnutrition and disease (Sheffield and Landrigan 2011).

As discussed in the MY 2014–2018 HD Final EIS, climate change is also projected to have psychological impacts. An increased frequency of extreme weather events and the likely competition for natural resources will contribute to stress and anxiety (Friel et al. 2011). Natural disasters such as Hurricane Katrina have caused post-traumatic stress disorder in addition to higher instances of depression and drug and alcohol abuse (Friel et al. 2011, Doherty and Clayton 2011 citing Anderson 2001).

5.5.7.2 Adaptation

As discussed above, it is becoming increasingly important for countries to address the impacts of climate change on human health through adaptation policies and strategies (Huang et al. 2011 citing WHO 2009). High-income countries, such as the United States, are more likely to have longer-term adaptation strategies with high governmental participation, such as increasing awareness, monitoring, and enhanced research, whereas low income countries are expected to take more reactive adaptation measures at the individual level, such as retreating, adjusting, and securing resources (Berrang-Ford et al. 2011).

Harlan and Ruddell (2011) examined risk management strategies for various major cities throughout the United States that will help combat the effects of climate change on human health, including heat and health watch warning systems, air quality monitoring and alert systems, and urban forests, which will help increase shade and reduce heat-related illnesses. To ensure food security and prevent malnutrition due to climate change, Friel et al. (2011) suggest new food production techniques, improved food storage facilities to withstand extreme weather, and new crop varieties.

5.5.8 Tipping Points and Abrupt Climate Change

5.5.8.1 Recent Findings

This section provides an overview of recent findings regarding observed and projected impacts of climate change on tipping points and abrupt climate change. For information on previously reported findings, *see* Section 4.5.9 (*Tipping Points and Abrupt Climate Change*) of the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS. These findings are drawn primarily from the following major international or national scientific assessment reports: U.S. Climate Change Science Program and the Subcommittee on Global Change Research's *Abrupt Climate Change* (CCSP 2008g); IPCC *Fourth Assessment Report* (IPCC 2007a, IPCC 2007b, IPCC 2007c); EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act* (EPA 2009e); NRC's *America's Climate Choices: Adapting to the Impacts of Climate Change* (NRC 2010e); NRC's *America's Climate Choices: Advancing the Science of Climate Change* (NRC 2010c), and *The Copenhagen Diagnosis* (Allison et al. 2009). In addition, Lenton et al. (2008), a peer reviewed article, was an important resource for this discussion.

The following sections summarize recent scientific findings associated with specific systems that potentially have a tipping point, as well as the broader issues regarding decisionmaking in light of emerging knowledge about tipping points and abrupt climate change.

"Tipping points" refer to thresholds within Earth systems that could be triggered by continued increases in the atmospheric concentration of GHGs, incremental increases in temperature, or other relatively small or gradual changes related to climate change. Earth systems that contain a tipping point exhibit large or accelerating changes, or transitions to a new physical state, which are significantly different than the rates of change or states that have been exhibited in the past. Examples of tipping points in Earth systems include rapid melting or permanent loss of Arctic sea ice, the Greenland ice sheet, and the West Antarctic ice sheet; slowing of the Atlantic Meridional Overturning Circulation (AMOC); changes in the behavior of the El Niño-Southern Oscillation (ENSO); changes in the Indian summer monsoon or the West African monsoon; increased forest dieback in the Amazonian rainforest; die-off events in boreal forests; changes in the behavior of dust storms in the Bodélé Depression at the southern edge of the Sahara Desert; rapid releases of CH_4 to the atmosphere from undersea hydrates or melting permafrost; and large-scale changes in precipitation and the hydrologic cycle.

Recent literature (e.g., Lenton 2011 and Lenton and Schellnhuber 2011) provides an overview of various potential tipping points, focusing largely on the set of systems outlined above (e.g., ice sheet loss, slowing of AMOC, and changes in ENSO). These tipping points were discussed in Section 4.5.9 of the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS and continue to form the core of the discussion in the literature.

As part of their reviews of the scientific literature, Lenton (2011) and Lenton and Schellnhuber (2011) offer some estimates for the range of temperatures at which certain tipping points might be crossed and the likelihood of such a crossing occurring before 2100; however, these risk assessments are largely qualitative. The temperature ranges are typically broad and subject to large uncertainty but indicate that global average temperature increases of 1 to 3 °C (1.8 to 5.4 °F) above pre-industrial levels could threaten the stability of the Greenland ice sheet, Arctic sea ice coverage, and the Hindu-Kush-Himalaya-Tibetan glaciers (Lenton 2011). Temperature increases above 3 °C increase the risk of triggering large-scale discontinuities, and there is general agreement among recent studies (Schellnhuber 2009, Lenton and Schellnhuber 2011, McNeall et al. 2011) that these risks, although difficult to quantify, grow with greater anthropogenic warming.

5.5.8.1.1 Arctic Sea Ice

Earlier research cited in the MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS identified Arctic sea ice coverage as a part of the climate system with a potential tipping point. Statistical measurements of Arctic sea ice suggest that ice coverage is declining at a faster rate in recent decades and could be exhibiting a non-linear response to warmer air temperatures, which is characteristic of a tipping point or abrupt change in system behavior. Sea-ice declines might also have a primary role in the rapid temperature increases the Arctic is experiencing compared to the global average (a phenomenon known as "arctic amplification") (Screen and Simmonds 2010). This relationship between the loss of sea ice and regional temperature is an example of the ice-albedo feedback;[66] such feedbacks are a potential characteristic of a system that possesses a tipping point or is capable of exhibiting abrupt changes. Recent studies have presented a synthesis of current Arctic sea ice research (Stroeve et al. 2011a), examined the response of arctic sea ice to a period of favorable conditions for ice retention in 2009 and 2010 (Stroeve et al. 2011b), and evaluated the potential for abrupt losses of Arctic sea ice (Holland 2010, Eisenman and Wettlaufer 2009, Wang and Overland 2009).

Since satellite observations of Arctic sea ice began in 1979, a significant decline in the extent of summer sea ice[67] has been observed, with the record minimum extent recorded in 2007. The relatively steep decline has motivated discussion of the potential timing of the Arctic becoming ice-free during the summer at some point in the twenty-first century, potentially by 2030 (Stroeve et al. 2008). Despite a slight rebound in sea-ice extent in September 2009, which was due in part to a favorable shift in the atmospheric circulation for sea-ice retention during the previous winter (Stroeve et al. 2011a), the large melting events in recent years have increased the amount of thinner, younger sea ice across the Arctic in the springtime, which can increase the ice's overall vulnerability to melting (Holland 2010, Stroeve et al. 2011a). This vulnerability is expected to increase the year-to-year variability exhibited by Arctic sea ice (Holland 2010), because the ice is likely to exhibit an enhanced response to intrinsic climate variability. However, it is not clear whether this increase in variability is best classified as a "threshold response" or simply an "abrupt change" (Holland 2010). Regardless, the continuation of warming in the Arctic lowers the likelihood of a substantial future recovery in the extent of Arctic sea ice (Stroeve et al. 2011b).

5.5.8.1.2 Greenland and West Antarctic Ice Sheets

The MY 2012–2016 CAFE standards Final EIS and the MY 2014–2018 HD Final EIS summarized research evaluating the possible timing and sea-level rise effects of the collapse of the Greenland and West Antarctic ice sheets. Recent research has summarized the current state of knowledge and observed changes in the rate of mass loss from these ice sheets (Lenton and Schellnhuber 2011, Good et al. 2011).

The Greenland and West Antarctic ice sheets are currently losing mass (Lenton and Schellnhuber 2011, Good et al. 2011, Chen et al. 2009). Recent estimates using a longer time series of polar ice-sheet mass measurements and improved error-correction techniques have found that East Antarctica ice sheets are also loosing mass, whereas previous estimates showed no change or slight increases in mass in East Antarctica (Chen et al. 2009). Large,

[66] Ice-albedo feedback refers to how changes in ice coverage can affect reflectivity in such a way as to reinforce the initial change in ice coverage. For example, as sea ice coverage is reduced, the exposed areas of ocean will absorb more incoming solar energy (i.e., ocean water has a lower albedo than ice), raising temperatures. This warming will lead to further losses of ice. The opposite case, involving an increase in ice coverage and cooling, is also a self-reinforcing mechanism.

[67] The September sea-ice extent is typically considered the annual minimum in ice extent. It should be noted that discussion of the September sea-ice extent (or late summer sea-ice extent) is simply one metric of the impact of sea ice on climate. The loss of sea ice can have impacts on regional climate during subsequent months (e.g., thinner ice and ice-free areas in the fall and winter allow for more heat to be transferred from the ocean to the atmosphere) and in future years (e.g., thinner or less ice in one season may contribute to thinner or less ice in a following season).

rapid losses of these ice sheets can have substantial consequences for sea-level rise. Uncertainties in the dynamics of melt in Greenland and West Antarctica are an important contributor to the uncertainty in overall estimates of sea-level rise in the future (*see* Section 5.1.6). Although there are significant uncertainties in our understanding of the mechanisms associated with abrupt ice loss, future rates of ice loss, and subsequent sea-level rise, scientists who convened for a recent workshop to discuss the state of the science agreed that, "ice sheets are capable of highly nonlinear dynamical behavior that could contribute significantly to short-term sea-level rise (to 2100), and may also produce a long-term commitment (e.g., centuries-long) to substantial (many meters) of [sic] sea-level rise" (IPCC 2010).

5.5.8.1.3 Ecological Tipping Points

Examples of ecological tipping points could include dramatic changes in ecosystem functions and productivity, levels of biodiversity, or species populations in response to abrupt or incremental climate changes. Work by Warren et al. (2011) reviews a wide range of studies that examine the impacts of warming on ecosystems around the globe. For increases in global mean temperature below 2 °C (3.6 °F), most impacts are related to changes in species' ranges and enhanced degradation of biodiversity hotspots (i.e., areas with a high concentration of diverse species that are threatened by human activities), such as coral reefs. Above the 2 °C warming threshold, negative impacts to ecosystems are projected to become more widespread, with greater risks for the collapse of ecosystems and extinction of species. In addition, many ecosystems and land areas that have served as net sinks of CO_2 could transition to become sources, acting as a positive feedback to global warming (Warren et al. 2011).

Salazar and Nobre (2010) recently investigated critical thresholds for biome shifts in the Amazonian tropical rainforest. The authors found that, without accounting for CO_2 fertilization, seasonal forests or savanna would replace the tropical rainforest in response to changes in precipitation and temperature, given a global average temperature increase of 2 to 3 °C (3.6 to 5.4 °F). However, when accounting for CO_2 fertilization, the changes in Amazonian tropical rainforest biome were "considerably smaller," suggesting that the CO_2 fertilization effect could play an important role in mitigating these impacts. The authors note that the response of tropical ecosystems to atmospheric CO_2 increases is a key area of uncertainty and that more research is necessary to reduce the uncertainty in projected shifts in Amazonian tropical forest biomes.

Recent research by Williams et al. (2011) documents examples of abrupt ecological changes from the paleo-climatological record. These events indicate that ecological systems can experience rapid change in response to abrupt climate change (extrinsically forced ecological change), or arising from internal dynamics (intrinsically forced ecological change) in which the climate forcing could have been relatively small or gradual. Each of these types of events is instructive for considering adaptation to future impacts of climate change; the impacts of extrinsically forced changes relate to the limits to adaptive capacity within ecological systems, while the results of intrinsically forced changes depend on site-specific conditions and the magnitude of other types of stressors (Williams et al. 2011).

5.5.8.1.4 Human-Environment Tipping Points

Human-environment tipping points could involve abrupt changes in socioeconomic systems (e.g., economic, societal, or political systems) in response to ecological shifts and regime changes. Recent modeling experiments by Horan et al. (2011) suggest that the rules established and enforced by institutions have an important role in establishing the nature of tipping points in managed human-environmental systems. This study investigated a simplified model involving simulation of the behavior of sportfishermen and the abundance of multiple freshwater species, subject to scenarios for management of the fish harvest rules. Horan et al. (2011) conclude that strong institutions – those with the ability to monitor and adjust to environmental and resource conditions – can best avoid abrupt changes and the crossing of tipping points.

Separately, Sherwood and Huber (2010) examined temperature thresholds at which humans would be unable to adapt to climate change-induced warming. They conclude that a global average temperature increase of 7 °C (12.6 °F) would create certain small areas so hot that humans would be unable to dissipate enough heat to regulate their own body temperatures. A temperature increase of 12 °C (21.6 °F) – which could occur if all available fossil fuels were combusted – would cause large portions of the eastern United States, South America, North and West Africa, the Middle East, eastern Asia, and Australia to become uninhabitable.

5.5.8.1.5 Delaying Mitigation

One recent study (Anderson and Bows 2011) reinforces the findings cited in the MY 2014–2018 HD Final EIS, which concluded that delaying mitigation requires more stringent reductions in the future to limit climate change impacts. Anderson and Bows (2011) apportioned global cumulative emissions assessments into emission pathways for Annex 1 and non-Annex 1 countries and found that global emissions of GHGs, and anticipated rates of future emissions, have made it difficult to restrict increases in the global mean temperature to 2 °C (3.6 °F) or less.

5.5.8.1.6 Methane Hydrates

Archer et al. (2009b) estimate that a uniform 3 °C (5.4 °F) increase in ocean temperature could release between 30 and 940 petagrams of carbon trapped in methane hydrates. A key parameter is the “critical bubble fraction” – a measure of the volume of bubbles at which gas begins to escape from sea-floor sediments. The higher end of these estimates would increase warming in the atmosphere by an additional 0.5 °C (0.9 °F), persisting for thousands of years. There are still large uncertainties associated with methane release mechanisms, but the authors conclude that sufficient fossil fuel reserves exist to destabilize a significant fraction of methane hydrates in the ocean.

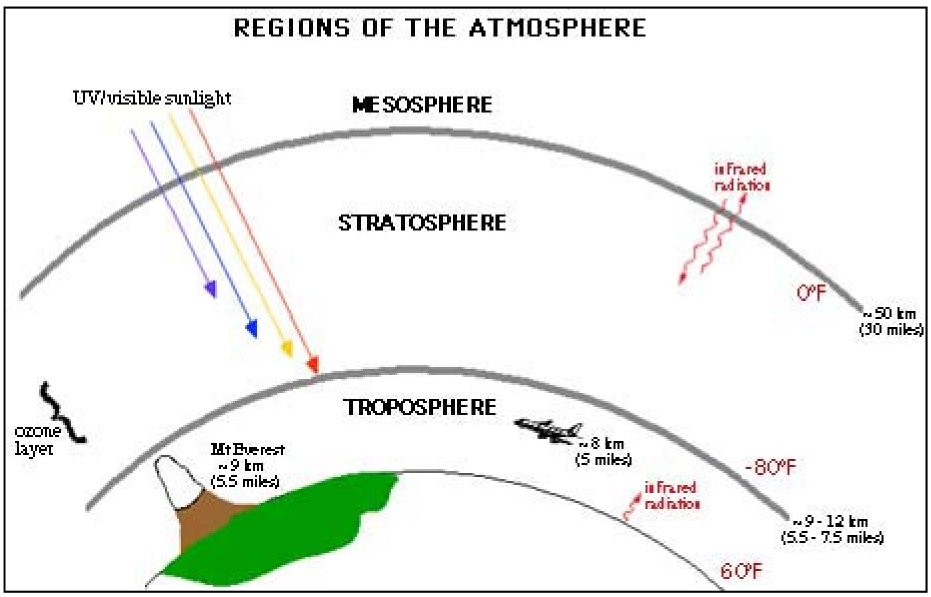
5.5.9 CO_2 and Climate Change Impacts on Stratospheric Ozone

Ozone in Earth’s stratosphere (the upper layer of the atmosphere) absorbs some harmful ultraviolet (UV) radiation from the sun, and therefore protects humans and other organisms (*see* Figure 5.5.9-1). Since the 1980s, satellite and ground observations have shown reductions in the concentrations of stratospheric ozone. There is an international consensus that man-made ozone-depleting substances (such as gases emitted by air conditioners and aerosol sprays) are responsible, prompting the establishment of international agreements to reduce the consumption and emission of these substances (Fahey and Hegglin 2011). In response, the rate of stratospheric ozone reduction has slowed. Although there are elements of uncertainty, stratospheric ozone concentrations are projected to recover over the next several decades to pre-1980 levels (Fahey and Hegglin 2011, WMO 2011).

Climate change could influence the recovery of stratospheric ozone. Although GHGs, including CO_2, warm the troposphere (the lower layer of the atmosphere), this process actually cools the stratosphere, slowing the chemical reactions between stratospheric ozone and ozone-depleting substances, hence assisting in ozone recovery. However, for polar regions, cooling temperatures can increase winter-time polar stratospheric clouds that are responsible for accelerated ozone depletion. Climate change will enhance atmospheric circulation patterns that affect stratospheric ozone concentrations, also assisting in ozone recovery in the extra-tropics. Changes in stratospheric ozone, in turn, influence climate by affecting the atmosphere's temperature structure and atmospheric circulation patterns (Ravishankara et al. 2008). In sum, climate change has been projected to have a direct impact on stratospheric ozone recovery, although there are large elements of uncertainty within these projections.

This section discusses the interaction of stratospheric ozone, climate, and trace gases using information provided by the World Meteorological Organization (WMO) *Scientific Assessment of Ozone Depletion: 2010* (WMO 2011), and the U.S. Climate Change Science Program (2008) report, *Trends in emissions of ozone-depleting substances, ozone layer recovery, and implications for ultraviolet radiation exposure* (CCSP 2008h).

Figure 5.5.9-1. The Three Lowest Layers in Earth's Atmosphere and the Location of the Ozone Layer[a]



a. Source: NOAA 2011b.

Ozone is a molecule consisting of three oxygen atoms. Ozone near Earth's surface is considered an air pollutant that causes respiratory problems in humans and adversely affects crop production and forest growth (Fahey and Hegglin 2011). Conversely, ozone in Earth's stratosphere (approximately 9 to 28 miles above Earth's surface) acts as a shield to block UV rays from reaching Earth's surface (Ravishankara et al. 2008).[68] This part of the atmosphere is sometimes referred to as the "ozone layer," and it provides some protection to humans and other organisms from exposure to biologically damaging UV rays that can cause skin cancer and other adverse effects (Fahey and Hegglin 2011, Fahey et al. 2008).

[68] These height measurements defining the bottom and top of the stratosphere vary depending on location and time of year. Different studies might provide similar but not identical heights. The heights indicated for the stratosphere and the layers within the stratosphere are provided in this section as defined by each study.

Ozone in the stratosphere is created when a diatomic oxygen molecule absorbs UV rays at wavelengths less than 240 nanometers, causing the molecule to dissociate into two very reactive free radicals that then each combine with an available diatomic oxygen molecule to create ozone (Fahey and Hegglin 2011). Through this process, heat is released, warming the surrounding environment. Once ozone is formed, it absorbs incoming UV rays with wavelengths between 220 and 330 nm (Fahey and Hegglin 2011). Ozone, which is a very reactive molecule, may also react with such species as hydroxyl radical, nitric oxide, or chlorine (Fahey et al. 2008).

The concentration of ozone in the stratosphere is affected by many factors, including concentrations of ozone-depleting substances and other trace gases, atmospheric temperatures, transport of gases between the troposphere and the stratosphere, and transport within the stratosphere. Many of these factors are affected by changes in climate and are discussed below.

Man-Made Ozone-depleting Substances and Other Trace Gases. For the past few decades, stratospheric ozone concentrations have been declining in response to increasing concentrations of man-made ozone-depleting substances. Examples of ozone-depleting substances include chlorofluorocarbons (CFCs) and compounds containing bromine (Ravishankara et al. 2008, Fahey and Hegglin 2011). These ozone-depleting substances are chemically inert near Earth's surface, but decompose into very reactive species when exposed to UV radiation in the stratosphere.[69] In 1987, an international agreement, *the Montreal Protocol on Substances that Deplete the Ozone Layer*, was established to reduce the consumption and production of man-made ozone-depleting substances in order to protect and heal the ozone layer and rebuild the ozone hole.[70] Subsequent agreements have followed that incorporate more stringent reductions of ozone-depleting substances and expand the scope to include additional chemical species that attack ozone. Some ozone-depleting substances, such as CFCs, are potent GHGs; therefore, reducing the emissions of these gases also reduces radiative forcing, and hence, reduces the heating of the atmosphere).

Increases in the emissions of other trace gases (e.g., methane and nitrous oxide) and CO_2 affect stratospheric ozone concentrations (Fahey et al. 2008). When methane is oxidized in the stratosphere, it produces water. Increases in stratospheric water lead to an increase in reactive molecules that assist in the reduction of ozone and an increase in polar stratospheric clouds that accelerate ozone depletion. Increases in N_2O emissions cause a reduction of ozone in the upper stratosphere as N_2O breaks down into reactive ozone-depleting species. CO_2 emissions affect atmospheric temperature; its impact on stratospheric ozone is discussed below.

Changes in Atmospheric Temperature. Since the observational record began in the 1960s, global stratospheric temperatures have been decreasing in response to ozone depletion, increased CO_2, and changes in water vapor (Fahey et al. 2008). Natural concentrations of

[69] For example, when a chlorofluorocarbon (CFC) molecule is exposed to UV radiation, it splits into a number of species, including a very reactive chlorine atom. The chlorine atom then combines with ozone, creating chlorine monoxide radical and a diatomic oxygen molecule. The chlorine monoxide radical can react with an oxygen atom (i.e., keeping the oxygen atom from reacting with diatomic oxygen to form ozone), creating the chlorine atom and another diatomic oxygen molecule. In essence, one chlorine atom has interrupted the natural ozone-producing cycle by consuming both a reactive oxygen atom and destroying an ozone molecule (Fahey and Hegglin 2011).

[70] The polar regions experience the greatest reduction in total ozone, with about a 5 percent reduction in the Arctic and 18 percent reduction in the Antarctic (Fahey and Hegglin 2011). Significant thinning in the ozone layer has been observed above the Antarctic since the spring of 1985, to such a degree it is termed the "ozone hole" (Ravishankara et al. 2008). This location is particularly susceptible to ozone loss due to a combination of atmospheric circulation patterns, and the buildup of ozone-depletion precursors during the dark winter months from June to September.

GHGs increase the warming in the troposphere (by absorbing outgoing infrared radiation; increasing GHG concentrations in the troposphere traps more heat in the troposphere, which translates to less incoming heat into the stratosphere. In essence, as GHGs increase, the stratosphere is projected to cool However, model simulations suggest reductions in ozone in the lower to middle stratosphere (13 to 24 miles) create a larger decrease in temperatures compared to the influence of GHGs (Fahey et al. 2008 citing Ramaswamy and Schwarzkopf 2002). Above about 24 miles, both the reductions of ozone and the impact of GHGs can contribute significantly to stratospheric temperature decreases.

The cooling temperatures in the stratosphere could slow the loss of ozone (Fahey et al. 2008). In the upper stratosphere, the dominant reactions responsible for ozone loss slow as temperatures cool. For example, ozone in the upper stratosphere is projected to increase by 15 to 20 percent under a doubled CO_2 environment (Fahey et al. 2008 citing Jonsson et al. 2004). In the lower stratosphere, where transport plays an important role both within the stratosphere and between the troposphere and stratosphere, cooling temperatures have less influence on ozone concentrations (except in the polar regions). Since 1993, ozone in the lower stratosphere above the Arctic has been greatly affected by cooling temperatures, as cooling has led to an increase in polar stratospheric clouds (Fahey et al. 2008). Polar stratospheric clouds play a significant role in reducing ozone concentrations. Ozone in the lower stratosphere above the Antarctic does not demonstrate such a significant response to cooling temperatures, because this region already experiences temperatures cold enough to produce these clouds.

Circulation and Transport Patterns. The large-scale Brewer-Dobson circulation represents the transport between the troposphere and stratosphere: an upward flux of air from the troposphere to the stratosphere occurs in the tropics balanced by a downward flux of air in the extratropics. This circulation carries stratospheric ozone from the tropics poleward.

Models suggest that the reduction of ozone above Antarctica is responsible for strengthening the circulation of stratospheric circumpolar winds of the wintertime vortex (i.e., the establishment of the vortex leads to significant ozone loss in late winter/early spring) (Fahey et al. 2008 citing Gillet and Thompson 2003, and Thompson and Solomon 2002).[71] Observations have shown that these winds can extend through the troposphere to the surface, leading to cooling over most of Antarctica. These studies suggest changes in stratospheric ozone can impact surface climate parameters.

Trends and Projections. Observations of global ozone concentrations in the upper stratosphere have shown a strong and statistically significant decline of approximately 6 to 8 percent per decade from 1979 to the mid 1990s, and a near zero or slightly positive trend thereafter (WMO 2011). Observations of global ozone within the lower stratosphere demonstrate a slightly smaller but statistically significant decline of approximately 4 to 5 percent per decade from 1979 to the mid 1990s (WMO 2011). The depletion of stratospheric ozone has been estimated to cause a slight radiative cooling of approximately -0.05 watts per square meter with a range of minus 0.15 to plus 0.05 watts per square meter, although there is great uncertainty in this estimate (Ravishankara et al. 2008).

[71] During the polar winter, a giant vortex with wind speeds exceeding 300 kilometers (186 miles) per hour can establish above the South Pole, acting like a barrier that accumulates ozone-depleting substances. In Antarctic springtime, temperatures begin to warm and the vortex dissipates. The ozone-depleting substances, now exposed to sunlight, release large amounts of reactive molecules that significantly reduce ozone concentrations (Fahey and Hegglin 2011).

The WMO (2011) used 17 coupled chemistry-climate models to assess how total column ozone (i.e., the total ozone within a column of air from Earth's surface to the top of the atmosphere) and stratospheric ozone will change in response to climate change and reductions in ozone-depleting substances. Under a moderate emission scenario (A1B), the model ensemble suggests changes in climate will accelerate the recovery of total column ozone. Projected ozone concentrations are compared to 1980 baseline conditions. Significant ozone reduction occurred between 1980 and approximately 2000. The model ensemble suggests the northern mid-latitudes total column ozone will recover to 1980 levels between 2015 to 2030, and the southern mid-latitudes total column ozone will recover between 2030 and 2040. Overall, the recovery of total ozone in the mid-latitudes to 1980 levels is projected to occur 10 to 30 years earlier due to climate change. The Arctic has a similar recovery time to 1980 conditions, while the Antarctic will regain 1980 concentrations around mid-century(because the chemistry-climate models underestimate present-day Arctic ozone loss, the modeled Arctic recovery period might be optimistic). The recovery is linked to impacts of climate that affect total column ozone, including (1) increased formation of ozone in the mid-to-upper stratosphere in response to cooling temperatures, (2) accelerated ground-level ozone formation in the troposphere as it warms, and (3) an accelerated Brewer-Dobson circulation increase in ozone transport in the lower stratosphere from the tropics to the mid-latitudes (WMO 2011).

In another study, doubled CO_2 concentrations simulated by 14 climate-change models project a 2 percent trend increase per decade in the annual mean troposphere-to-stratosphere exchange rate. This acceleration could affect long-lived gases such as CFCs, methane, and nitrous oxide by reducing their lifetime and increasing their removal from the atmosphere. In addition, this could increase the vertical transport of ozone concentrations from the stratosphere to the troposphere over mid-latitude and polar regions (Fahey et al. 2008 citing Butchart and Scaife 2001).

5.6 Non-climate Cumulative Impacts of Carbon Dioxide

5.6.1 Background

In addition to its role as a GHG in the atmosphere, CO_2 is exchanged between the atmosphere and water, plants, and soil. CO_2 readily dissolves in water, combining with water molecules to form carbonic acid. The amount of CO_2 dissolved in the upper ocean is related to its concentration in the air. About 30 percent of each year's emissions (Canadell et al. 2007) dissolves in the ocean by this process; as the atmospheric concentration continues to increase, the amount of CO_2 dissolved will increase. Although this process moderates the increase in the atmospheric concentration of CO_2, it also increases the acidity of the ocean. Increasing CO_2 concentrations in the atmosphere and surface waters will have a global effect on the oceans; by 2100, the average ocean pH could drop by 0.3 to 0.4 unit compared to ocean pH today (Caldeira and Wickett 2005, Feely et al. 2009).

Terrestrial plants remove CO_2 from the atmosphere through photosynthesis, using the carbon for plant growth. This uptake of carbon by plants can result in an atmospheric CO_2 concentration approximately 3 percent lower in the growing season than in the non-growing season (Perry 1994 citing Schneider and Londer 1984). Increased levels of atmospheric CO_2 essentially act as a fertilizer, positively influencing normal annual terrestrial plant growth. Over recent decades, terrestrial carbon uptake has been equivalent to approximately 30 percent of each year's CO_2 emissions (Canadell et al. 2007); so this process is about equal to CO_2 dissolution in ocean waters in moderating the effect of increasing CO_2 emissions on the atmospheric CO_2 concentration.

In addition, atmospheric CO_2 concentration affects soil microorganisms. Only recently has the relationship between aboveground and belowground components of ecosystems been considered significant; there is increasing awareness that feedbacks between the aboveground and belowground components play a fundamental role in controlling ecosystem processes. For example, plants provide most of the organic carbon required for belowground decomposition. Plants also provide the resources for microorganisms associated with roots (Wardle et al. 2004). The "decomposer subsystem in turn breaks down dead plant material, and indirectly regulates plant growth and community composition by determining the supply of available root nutrients" (Wardle et al. 2004).

Specific plant species, depending on the quantity and quality of resources provided to belowground components, might have greater impacts on soil biota and the processes regulated by those biota than other plants. Variations in the quality of forest litter produced by coexisting species of trees, for example, "explains the patchy distribution of soil organisms and process rates that result from 'single tree' effects" (Wardle et al. 2004). The composition of plant communities has a consistent and substantial impact on the composition of root-associated microbes. However, the effects of plant community composition on decomposer systems are apparently context-dependent. In one study, manipulating the composition of plant communities in five sites in Europe produced distinct effects on decomposer microbes, while root-related soil microbes experienced no clear effect (Wardle et al. 2004).

Terrestrial communities contain as much carbon as the atmosphere. Forest ecosystems, including forest soils, play a key role in storing carbon. The amount of carbon stored in soils of temperate and boreal forests is about four times greater than the carbon stored by vegetation, and is "33 percent higher than total carbon storage in tropical forests" (Heath et al. 2005). Forest soils are the longest-lived carbon pools in terrestrial ecosystems (King et al. 2004).

Several experiments involving increases of atmospheric CO_2 resulted in increasing carbon mass in trees but a reduction of carbon sequestration in soils. This observation is attributable to increased soil microorganism respiration (Heath et al. 2005, Black 2008); respiration is associated with "root herbivory, predation, consumption of root exudates, and the decomposition of root and leaf litter" (King et al. 2004). Under climate change, the reduction of soil carbon via increased soil respiration could be counterbalanced by an increase in litter on the forest floor due to increased productivity. However, one recent study suggests that while increasing carbon could increase root production, it could decrease the quality of forest litter (Pritchard 2011).

5.6.2 Environmental Consequences

Sections 5.6.2.1 and 5.6.2.2 provide a qualitative analysis of non-climate cumulative impacts of CO_2.[72] As with the climatic effects of CO_2, the changes in non-climate impacts associated with the alternatives are difficult to assess quantitatively. Nonetheless, it is clear that a reduction in the rate of increase in atmospheric CO_2, which all the action alternatives would provide to some extent, would reduce non-climate impacts of CO_2, such as the ocean acidification effect and the CO_2 fertilization effect described in Section 5.6.2.1.

5.6.2.1 Ocean Acidification

Ocean acidification occurs when CO_2 dissolves in seawater, initiating a series of chemical reactions that increases the concentration of hydrogen ions and makes seawater less basic (and therefore more acidic) (Bindoff et al. 2007, Menon et al. 2007, Doney et al. 2009a, Feely et al. 2009). An important consequence of this change in ocean chemistry is that the excess hydrogen ions bind with carbonate ions, making the carbonate ions unavailable to marine organisms for forming the calcium carbonate minerals (mostly aragonite or calcite) that make up their shells, skeletons, and other hard parts. Once formed, aragonite and calcite will re-dissolve in the surrounding seawater, unless the water contains a sufficiently high concentration of carbonate ions (recent reviews by Doney 2009c, Doney et al. 2009b, EPA 2009e, Fabry et al. 2008, Fischlin et al. 2007, Guinotte and Fabry 2008, The Royal Society 2005, SCBD 2009).

For many millennia before present, ocean pH changed little. Even during the warm Cretaceous period, about 100 million years ago, when atmospheric CO_2 concentrations were between 3 and 10 times higher than at present, it is considered unlikely that there was a significant decrease in ocean pH. This is because the rate at which atmospheric CO_2 changed in the past was much slower than at present, and during slow natural changes, the carbon system in the oceans has time to reach a steady state with sediments. If the ocean starts to become more acidic, carbonate will be dissolved from sediments, buffering the chemistry of the seawater so that pH changes are lessened (The Royal Society 2005).

As anthropogenic emissions have increased, CO_2 in the atmosphere has accumulated and a net flux of CO_2 from the atmosphere to the oceans has occurred. As a result, the pH and carbonate ion concentrations of the world's oceans have declined and are now lower than at any time in the past 420,000 years (Hoegh-Guldberg et al. 2007). Ocean pH today is estimated to have declined in relation to the pre-industrial period by 0.1 pH units (on a logarithmic scale), representing a 30 percent increase in ocean acidity (Caldeira and Wickett 2003, EPA 2009e).

[72] *See* U.S.C. § 4332 (requiring federal agencies to "identify and develop methods and procedures…which will insure that presently unquantified environmental amenities and values may be given appropriate consideration"); CEQ (1997) (recognizing that agencies are sometimes "limited to qualitative evaluations of effects because cause-and-effect relationships are poorly understood" or cannot be quantified).

Regionally, high-latitude ocean water has exhibited greater reduction in pH due to low buffer capacity, compared to low-latitude ocean water.

Feely et al. (2004) predict that as early as 2050, ocean pH could be lower than at any time during the past 20 million years. This rate of change is at least a hundred times greater than during the past hundreds of millennia (The Royal Society 2005). By 2100, depending on the emission scenario modeled, the average ocean pH could decline by another 0.3 to 0.4 pH units from today's levels (Fischlin et al. 2007, Doney et al. 2009a, EPA 2009e, Feely et al. 2009). The current atmospheric concentration of CO_2 (389 ppm per NOAA 2011a) is already more than 38 percent higher than pre-industrial levels (EPA 2009e). Further increases will have significant consequences for marine life (Doney et al. 2009b). In fact, Caldeira et al. (2007) estimated that atmospheric CO_2 would need to be stabilized below 500 ppm for the change in locally measured ocean pH to remain below the limit of 0.2 pH units of human-caused variation established in 1976 under Clean Water Act Section 304(a) to protect marine life (EPA 1976).

At present, the ocean's surface waters contain enough carbonate ions to sustain marine life. Approximately 42 percent of the ocean volume is saturated with respect to aragonite (a form of calcium carbonate) (Bindoff et al. 2007). The saturation horizon (the depth above which super-saturation occurs and within which most of the ocean's marine life occurs) is becoming shallower (Feely et al. 2004, 2009). As the ocean absorbs more CO_2 and ocean acidity increases, fewer carbonate ions will be available for organisms to use for calcification.

As the oceans absorb increasing amounts of CO_2, the greatest pH decline in the ocean's surface waters in relation to the global average will occur in polar and subpolar regions. CO_2 dissolves more readily in cold water, which is naturally low in carbonate ion concentration and more acidic than surface waters (Meehl et al. 2007). Orr et al. (2005) used 13 climate models of the ocean-carbon cycle to assess calcium carbonate saturation under the IPCC IS92a "business as usual" scenario (one of the six IPCC emission scenario alternatives developed in 1992) (Leggett et al. 1992). Under these model runs, Southern Ocean surface waters would begin to become undersaturated with respect to aragonite as early as 2050; by 2100 all of the Southern Ocean south of 60 degrees south and portions of the Subarctic North Pacific could become undersaturated (EPA 2009e). Simulation of the IPCC IS92a scenario predicted wintertime aragonite undersaturation in the Southern Ocean starting between 2030 and 2038 (McNeil and Matear 2008), with 10 percent of the area becoming undersaturated at least 1 month per year during this decade (Hauri et al. 2009). Simulation of the SRES A2 scenario (IPCC 2000) predicts aragonite undersaturation in Arctic surface waters once the atmospheric CO_2 concentration increases above 450 ppm (Steinacher et al. 2009). Under this scenario, the ocean volume that is saturated with respect to aragonite could decrease from approximately 42 percent today to 25 percent by 2100, resulting in a significant loss of marine life (Steinacher et al. 2009).

Recent observations indicate that ocean acidification is increasing in some areas faster than expected (Hauri et al. 2009). Hydrographic surveys have found that this differential acidification occurs, for example, when wind-induced upwelling of seawater undersaturated with respect to aragonite spreads out over the continental shelf; evidence of this is reported from western North America during unusual weather conditions, decades earlier than model predictions for average weather conditions (Feely et al. 2008, Hauri et al. 2009). Seasonal upwelling is also observed in the California Current System and the Humboldt Current System, and other eastern-boundary upwelling systems (Hauri et al. 2009). Measurements of ocean pH off the coast of Washington State over 8 years found that acidity in the region has increased more than 10 times faster than in other areas (Wootton et al. 2008). Because measurements in other parts of the ocean will not reflect this regional variability, there is concern that the more immediate vulnerability of marine organisms in upwelling areas might be overlooked (Hauri et al. 2009).

5.6.2.1.1 Impacts of Ocean Acidification on Marine Life

The results of most laboratory and field studies to date indicate that the reduction in calcium carbonate resulting from ocean acidification reduces the calcification rates of marine organisms, a finding that holds over a wide range of taxa (NRC 2010b). Studies also suggest that some species could benefit from conditions of low pH, at least during certain life stages. Responses of some groups, such as microbial communities, have received little attention to date, and findings thus far are unclear but potentially significant, given the importance of microbes for ocean biochemistry (Joint et al. 2010). A complex picture is emerging, indicating that there will be “winners” and “losers” in acidified oceans (Ries et al. 2009, NRC 2010b). Several important questions remain.

For example, if or how much acclimation or adaptation by marine organisms will occur is not yet known. Observations over sufficient time to determine the potential for genetic adaptation are lacking, and whether responses of individual species in laboratory and mesocosm studies can be extrapolated to populations in natural systems is not known. Also, little information is available on how key variables such as temperature, light, and nutrients might interact with acidification to influence calcification rates (Pandolfi et al. 2011).

There is also a need to improve understanding of how ocean acidification and other anthropogenic stressors interact (Boyd 2011). A recent modeling exercise by Anthony et al. (2011) examined how acidification and fishing pressure on herbivores might affect the ecological resilience of a simplified benthic reef community made up of corals and macroalgae. Resilience was defined by the reef’s capacity to maintain and recover to coral-dominated states. Results indicated that corals already subject to anthropogenic stressors that reduce growth and survival will show reduced resilience.

Some scientists have suggested that critical thresholds at which adverse effects occur as a result of elevated CO_2 could be relatively low for many animals (Pörtner et al. 2005). Veron et al. (2009) argue that CO_2 levels below 350 ppm are needed to protect coral reef ecosystems from collapse. Recent reviews of available studies are provided by Doney (2009c), Doney et al. (2009b), EPA (2009e), Fabry et al. (2008), Guinotte and Fabry (2008), Fischlin et al. (2007), The Royal Society (2005), Haugan et al. (2006), and (SCBD 2009). Details about the available literature are presented in Table 1 of Fabry et al. (2008), Table 2 of Guinotte and Fabry (2008), and Tables 2 and 3 of SCBD (2009). The following paragraphs provide representative results from the peer-reviewed literature as of September 1, 2011. Both modeling results and observations indicate that ocean acidification has adverse impacts on a variety of marine taxa ranging from the individual to ecosystem levels.

Warmwater Corals. Under the SRES A2 scenario, ocean waters with an aragonite saturation level suitable for coral growth are projected to disappear between 2050 and 2100 (Guinotte et al. 2006). Models of CO_2 concentrations up to 560 ppm (a doubling of pre-industrial levels), which could occur by mid-century, predicted a 20 to 60 percent decrease in the calcification rates of tropical reef-building corals, depending on the species (Guinotte and Fabry 2008, Hoegh-Guldberg et al. 2007, Kleypas et al. 1999). A recent study by Silverman et al. (2009) produced even more dramatic results, predicting that existing reefs could stop growing and start to dissolve once atmospheric concentrations reach the 560-ppm level. Other studies indicate that the percent decreases in calcification rates will be species- and life-stage specific (Cohen and Holcomb 2009, Kleypas and Yates 2009). Fine and Tchernov (2007) studied two species of coral that showed complete dissolution of their shells in highly acidified water but were able to regrow their shells when returned to water of normal pH. Langdon et al. (2000) and Leclercq et al. (2000) found that saturation state was the primary factor determining calcification rates of coral reef ecosystems grown in a large mesocosm (i.e., an outdoor containment). Krief et al. (2010) held fragments of two species of stony coral for 6 to 14 months at pH values of 8.09, 7.49, and 7.19, and found that although all of the coral survived and added new skeleton, skeletal growth and zooxanthellae density decreased, whereas coral tissue biomass and zooxanthellae chlorophyll concentrations increased under low pH. A recent mesocosm study of a subtropical coral reef community found that although the community as a whole showed reduced calcification in acidified waters, some individuals were able to continue calcification but at a reduced rate (Andersson et al. 2009).

A new study examined the effects of ocean acidification on early life history processes of the Caribbean coral *Porites astreoides*. Larvae were collected in ocean waters and observed in the laboratory at three levels of atmospheric CO_2: 380 microatmospheres (µatm) (ambient seawater), 560 µatm (projected seawater concentration mid-century), and 800 µatm (projected concentration end of century). Compared to controls, larval metabolism was depressed by 27 percent and 63 percent at 560 µatm and 800 µatm, respectively. Settlement was reduced by 42 to 45 percent at 560 µatm and 55 to 60 percent at 800 µatm. Post-settlement growth decreased by 16 percent at 560 µatm and 35 percent at 800 µatm. Other findings indicated that the reduction in settlement was an indirect effect of changes to the substrate community that reduced settlement cues, rather than a direct effect on the larvae themselves (Albright and Langdon 2011).

Measurement of the calcification rates of 328 corals from 69 reefs along the Great Barrier Reef showed a decline of 14.2 percent in calcification rates from 1990 to 2005. The researchers hypothesize that the main causes of the continuing decline are increased sea surface temperatures combined with a lower aragonite saturation state (De'ath et al. 2009). High CO_2 is also a bleaching agent for corals and crustose coralline algae under high irradiance and acts synergistically with warming to lower thermal bleaching thresholds (Anthony et al. 2008). The combined effects of increased CO_2 and bleaching events resulting from elevated sea surface temperatures have heightened concerns about the survival of tropical and subtropical corals worldwide (Hoegh-Guldberg et al. 2007, Kleypas and Yates 2009). Bleaching occurs when corals eject their symbiotic algae when the temperature of surface waters increases above a threshold near 30 °C (86 °F). Increases in sea surface temperatures have contributed to major bleaching episodes in subtropical and tropical coral reefs (EPA 2009e, Kleypas and Yates 2009). These bleaching events increase the risk of disease among surviving coral (EPA 2009e, Hoegh-Guldberg et al. 2007, Kleypas and Yates 2009). For example, in Virgin Islands National Park, 50 percent of the corals have died from bleaching or subsequent disease outbreaks (EPA 2009e). The IPCC concluded that it is *very likely* that a projected future increase in sea surface temperature of 1 to 3 °C (1.8 to 5.4 °F) will result in more frequent bleaching events and widespread coral mortality, unless there is long-term thermal adaptation by corals and their algal symbionts (Nicholls et al. 2007, EPA 2009e). A group of 39 coral experts from around the world estimated that one-third of reef-building corals face elevated risk of extinction (Carpenter et al. 2008).

The vulnerability of warm-water corals to thermal stress will also depend on the severity and extent of additional anthropogenic stressors, such as overfishing, pollution, invasive species, and available nutrients (EPA 2009e). For example, a recent analysis of 23 years of Chesapeake Bay water quality data showed significant reductions in oyster biocalcification in relation to a 0.5 unit decline in pH from pollution alone (Waldbusser et al. 2010). Cohen and Holcomb (2009) observed that global warming has increased ocean stratification, reduced the depth of the mixed layer, and slowed circulation, all of which reduce nutrient availability and therefore could magnify the adverse effects of ocean acidification. They noted that not only would this combination of effects reduce growth and calcification rates in corals, it could also reduce sexual reproduction and genetic diversity, interfering with adaptation mechanisms. A new field study in Puget Sound showed that acidification combined with excess nutrient runoff from polluted landscapes enhances growth of phytoplankton and zooplankton (Feely et al. 2010). Excess nutrients could increase eutrophication in the near term, while also increasing rates of acidification over time as the plankton die and decompose. In addition, the researchers observed that lowered seawater pH and hypoxia will have a synergistic effect on organisms that will be exacerbated by the combination of stressors they face, including ocean acidification, change in land uses, and eutrophication. As a result, affected organisms could reach the limits of their physiological tolerances and cross critical thresholds, with abrupt and major changes to ecosystem health.

***Coldwater Corals*.** As the aragonite saturation horizon (the limit between water that is saturated with aragonite and that which is undersaturated) becomes shallower, saturated waters are becoming limited to the warm surface layers of the world's oceans. As a result, under the IPCC IS92a (business as usual) scenario, which assumes countries do little to curb emissions (IPCC 2000), it is projected that by 2100, only 30 percent of existing coldwater corals will remain in saturated waters (Guinotte et al. 2006).

***Marine Algae*.** Crustose coralline algae are critical for coral reefs, because they cement carbonate fragments together. Under high CO_2 conditions in an outdoor mesocosm experiment, the recruitment rate[73] and percentage cover of crustose coralline algae decreased by 78 percent and 92 percent, respectively, whereas that of non-calcifying algae increased by only 52 percent (Kuffner et al. 2008).

Although some marine phytoplankton grow well over a wide range of pH, others have growth rates that vary greatly over a 0.5- to 1.0 pH unit change (Hinga 2002). Eutrophication and ocean acidification might interact to increase the frequency of blooms of those species that tolerate extreme pH (Hinga 2002).

Coccolithophores are tiny "shields" made from dozens of individual calcite crystals produced by some planktonic microalgae. Coccoliths – the main calcifiers in the ocean – show a mix of responses to ocean acidification. In one study, the coccolithophores on algae showed reduced calcification when grown in water in contact with air at 750 ppm CO_2 (Riebesell et al. 2000), although in another study they showed no change (Langer et al. 2006). In another laboratory study, photosynthesis and nitrogen fixation in some coccolithophores, prokaryotes, and cyanobacteria showed either no change or increases in water in contact with higher CO_2 (Doney et al. 2009a). A new study by Hassenkam et al. (2011) indicates that the organic material associated with the biogenic calcite in coccolithophores makes it more stable than inorganic calcite. However, once pH drops to 7.8 or lower, which is projected by 2100, biogenic calcite also dissolves.

***Mollusks*.** Gazeau et al. (2007) found that calcification in a mussel species and the Pacific oyster declined by 25 percent and 10 percent, respectively, when grown in seawater in contact with air at 740 ppm CO_2, which is the concentration expected by 2100 under the IPCC IS92a scenario. Two of the largest oyster hatcheries in the Pacific Northwest reported an 80 percent

[73] Recruitment rate refers to the number of new individuals added to a biological population.

decline in production rates since 2005, which could be the result of acidification of surface waters combined with lower pH water in the deeper ocean that is brought to the surface during the upwelling season (Miller et al. 2009). A study of the Sydney rock oyster found that fertilization declined significantly from the combined effects of acidification and temperature (Parker et al. 2009). Prolonged exposure to these stressors also impaired growth and survival of early developmental stages.

The effects of ocean acidification alone on an intertidal gastropod included slowed development and abnormal growth of early life stages. Within 14 to 35 days, there was significant dissolution in the shells of four species of Antarctic benthic mollusks (two bivalves, one limpet, one brachiopod) held in pH 7.4 seawater (McClintock et al. 2009). Barnacles exposed to the same low pH showed a trend of larger basal shell diameters during growth, which researchers suggest could indicate a compensatory response to declining pH (McDonald et al. 2009). Nonetheless, dissolution weakened shell walls as the barnacles grew. Shifts in community composition were observed in a mussel-dominated rocky intertidal community experiencing rapid declines in pH (0.4 pH units over 8 years). Years of low pH were accompanied by declines in calcareous species (e.g., mussels and stalked barnacles) and increases in non-calcareous species (e.g., acorn barnacles and algae) (Wootton et al. 2008).

Effects on species at high latitudes will likely be apparent earlier than in other areas, given the more rapid accumulation of acidification in these regions (Fabry et al. 2009). Pteropods, small marine snails that are ubiquitous at high latitudes, show shell dissolution in seawater undersaturated with respect to aragonite (Feely et al. 2004, Orr et al. 2005). When live pteropods were collected in the Subarctic Pacific and exposed to a level of aragonite undersaturation similar to that projected for the Southern Ocean by 2100 under the IPCC IS92a emission scenario, shell dissolution occurred within 48 hours (Orr et al. 2005). A 28 percent reduction in calcification was observed in one species of pteropod in response to pH levels expected by 2100 (Comeau et al. 2009). Declines in pteropods are a particular concern in oceans at high latitude, where they are a critical food source for marine animals ranging from krill (small shrimp-like organisms) to whales, and including highly valued fish such as salmon. Therefore, their loss could have significant effects on high-latitude food webs (Guinotte and Fabry 2008). Recent observations in the Gulf of Alaska, for example, show that pteropods are especially vulnerable in Alaska waters, which show higher acidification than elsewhere (Bates and Mathis 2009). Researchers estimated that a 10 percent decline in pteropod abundance in this region could mean a 20 percent decrease in an adult salmon’s body weight.

***Echinoderms*.** Some sea urchins show reduced early development (Kurihara and Shirayama 2004), shell growth (Shirayama and Thornton 2005), and fertilization success (Kurihara and Shirayama 2004, Reuter et al. 2011) in seawater with elevated CO_2 concentrations. However, a study by Byrne et al. (2010) found that fertilization and early development were unaffected by the levels of pH (0.2 to 0.4 pH units) and warming (2 to 4 °C) (3.6 to 7.2 °F) projected for the end of this century. Urchin embryos were sensitive to elevated temperature (Byrne et al. 2009).

Crustaceans. Laboratory studies of larval stages of the European lobster found physiological changes in calcification and carapace development in low-pH, high-acidity seawater (Arnold et al. 2009). Another study found that North American lobsters, crabs, and shrimp were able to build more shell as acidity increased (Ries et al. 2009). Changes in pH upset acid-base regulation in many animals, including crustaceans and fish, and affect processes that are important for growth and the control of neurotransmitter concentrations such as ion exchange, oxygen transport, and metabolic equilibria (Pörtner et al. 2004).

Marine Fish and Marine Mammals. The use of calcium minerals in gravity sensory organs is common in marine species at higher trophic levels. A study of responses to olfactory cues by clownfish larvae found that responses were impaired at pH 7.8 and below, interfering with the ability of the larvae to identify suitable settlement sites on reefs (Munday et al. 2010). A new study of clownfish showed that ocean acidification also impairs auditory responses in this species (Simpson et al. 2011). A study of predator detection by early life stages of another marine fish species found that when eggs and larvae were exposed to low-pH water, larvae at the settlement stage were unable to distinguish between predators and non-predators, and in some cases were actually attracted to the smell of predators (Dixson et al. 2010). Other studies suggest that high CO_2 in seawater can lead to cardiac mortality in some fish (Ishimatsu et al. 2004). Cooley and Doney (2009) observed that losses of calcifying organisms at the base of marine food webs will ultimately be transmitted to fish species of high ecological and economic value. While indirect effects via transmission through the food web is important, Haugan et al. (2006) reviewed a number of studies that show that there are also direct effects of elevated CO_2 on the growth, reproduction, and activity of higher tropic level organisms. For example, there is evidence that even a small decrease in pH has a dramatic effect on the oxygen carrying capacity of squid (Turley et al. 2006).

***Analogs*.** Some recent studies have examined geologic and natural analogs to help determine potential effects of ocean acidification on marine life. A period about 55 million years ago known as the Paleocene-Eocene thermal maximum (PETM) is considered the closest geological analog to today's oceans. During this time, a massive and rapid input of carbon to the atmosphere and ocean occurred. Marine plankton survived a period of intense warming and acidification, lasting 1,000 to 2,000 years. A new study that compared predicted future levels of ocean acidity with PETM conditions found that under the IPCC IS92a emissions scenario, the extent and rate of acidification in today's ocean is on track to greatly exceed that during the PETM (Ridgwell and Schmidt 2010). Moy et al. (2009) provided direct evidence that ocean acidification is affecting shell formation, finding that the shells of foraminifera in the current Southern Ocean are 30 to 35 percent lighter than shells of the same species in core samples from ocean sediments that predate the Industrial Revolution. Hall-Spencer et al. (2008) found that in near-subsurface vents, which have natural, volcanic release of CO_2, stony corals are not present and numbers of calcifying sea urchins, coralline algae, and gastropods are low.

5.6.2.1.2 Changes in the Effectiveness of the Ocean Sink

As CO_2 increases in surface waters and carbonate concentrations decline, the effectiveness of the ocean as a "sink" for CO_2 could decrease (Sabine et al. 2004, Le Quéré et al. 2009). In addition, ocean warming also decreases the solubility of CO_2 in seawater (Bindoff et al. 2007, Menon et al. 2007). Observations and modeling studies indicate that the large regional sinks in the North Atlantic (Lefèvre et al. 2004, Schuster and Watson 2009), the Southern Ocean (Le Quéré et al. 2007, Lovenduski et al. 2008), and the North Sea have declined in recent decades (Fabry et al. 2009). Between 2000 and 2008, emissions increased by 29 percent. One study estimated that from 2000 to 2006, the oceans absorbed approximately 25 percent of anthropogenic CO_2 emissions, representing a decline in the ocean sink from 29 percent absorption in earlier decades (Canadell et al. 2007). Recently, Khatiwala et al. (2009) reconstructed the history of CO_2 concentrations in the ocean from 1765 to 2008 and found that ocean uptake has decreased by as much as 10 percent since 2000. Tans (2009) argued that although these findings could be true locally, the available data indicate that they do not apply globally. He concluded that the decrease in the rate of uptake of atmospheric CO_2, despite increased emissions, can only be explained if there has been a more effective uptake by the oceanic or terrestrial biosphere. Le Quéré et al. (2009) reported that over the past 50 years, the fraction of CO_2 emissions that remains in the atmosphere each year has increased from 40 percent to 45 percent, supporting the conclusions of Khatiwala et al. (2009) that there has been a decline in the oceanic uptake of CO_2. Recent modeling suggests that this results from the responses of carbon sinks to both climate change and climate variability (Le Quéré et al. 2009).

If climate variability is the primary cause, current trends might be short in duration and not signals of long-term climate change. However, the measurements by Khatiwala et al. (2009) indicate that the slowdown in the ocean uptake of carbon results from physical and chemical limits on the ocean's ability to absorb carbon. The researchers concluded that the more acidic the oceans become, the less they are able to absorb carbon. Other measurements of actual CO_2 concentrations found that in the Canada Basin in the Arctic in areas where sea ice had melted dramatically, uptake of carbon (measured in unit of CO_2 pressure at 120 to 150 micropascals) was well below atmospheric CO_2 pressure (375 micropascals), whereas in ice-free areas offshore, seawater pressure (320 to 360 micropascals) was much closer to atmospheric pressure (Yamamoto-Kawai et al. 2009, Cai et al. 2010). In the Chukchi Sea during the summertime retreat of sea ice, increased phytoplankton productivity decreases the concentration of CO_2 over the continental shelf, causing aragonite saturation states to increase, while deeper waters become undersaturated (Bates and Mathis 2009).

5.6.2.1.3 IPCC Conclusions about Ocean Acidification

The 2007 IPCC conclusions about ocean acidification are as follows (Menon et al. 2007, EPA 2009e):

- The biological production of corals, and calcifying phytoplankton and zooplankton in the water column, could be inhibited or slowed as a result of ocean acidification.
- Cold-water corals are likely to show large reductions in geographic range this century.
- The dissolution of calcium carbonate at the ocean floor will be enhanced, making it difficult for benthic calcifiers to develop protective structures.
- Acidification can influence the marine food web at higher trophic levels.

5.6.2.2 Plant Growth and Soil Microorganisms

In contrast to its potential adverse effect on the productivity of marine ecosystems, higher CO_2 concentrations in the atmosphere could increase the productivity of terrestrial systems. CO_2 can have a stimulatory or fertilization effect on plant growth (EPA 2009e). Plants use CO_2 as an input to photosynthesis. The IPCC Fourth Assessment Report states that "[o]n physiological grounds, almost all models predict stimulation of carbon assimilation and sequestration in response to rising CO_2, referred to as 'CO_2 fertilization'" (Menon et al. 2007). The IPCC projects with *medium* confidence that forest growth in North America will likely increase 10 to 20 percent, due to both CO_2 fertilization and longer growing seasons, over this century (EPA 2009e, Field et al. 2007).

In addition to EPA (2009e) noting the known fertilization effect of CO_2 on plant growth, several investigators have also found that higher CO_2 concentrations have a fertilizing effect on plant growth through bench-scale and field-scale experimental conditions (e.g., Long et al. 2006, Schimel et al. 2000). Through free air CO_2 enrichment experiments, at an ambient atmospheric concentration of 550 ppm CO_2, unstressed C_3 crops (e.g., wheat, soybeans, and rice) yielded 10 to 25 percent more than under current CO_2 conditions, while C_4 crops (e.g., maize) yielded up to

10 percent more (EPA2009e).[74] In addition, the IPCC reviewed and synthesized field and chamber studies, finding that:

> There is a large range of responses, with woody plants consistently showing net primary productivity increases of 23 to 25 percent (Norby et al. 2005), but much smaller increases for grain crops (Ainsworth and Long 2005). Overall, approximately two-thirds of the experiments show positive response to increased CO_2 (Ainsworth and Long 2005, Luo et al. 2004). Because saturation of CO_2 stimulation due to nutrient or other limitations is common (Dukes et al. 2005; Körner et al. 2005), the magnitude and effect of the CO_2 fertilization is not yet clear.

Forest productivity gains that might result through the CO_2 fertilization effect can be reduced by other changing factors, and the magnitude of this effect remains uncertain over the long term (EPA 2009e). Easterling et al. (2007) discussed studies suggesting that the CO_2 fertilization effect might be lower than previously assumed, with the initial increases in growth potentially limited by competition, disturbance (e.g., storm damage, forest fires, and insect infestation), air pollutants (primarily tropospheric ozone), nutrient limitations, ecological processes, and other factors (EPA 2009e). One study's results show that the magnitude of increased production was determined primarily by the availability of water and nitrogen, with greater CO_2-induced net primary productivity in environments with plentiful water and nitrogen (McCarthy et al. 2010).

The CO_2 fertilization effect could mitigate some of the increase in atmospheric CO_2 concentrations by resulting in more storage of carbon in biota. It should also be noted that although CO_2 fertilization can result in a greater mass of available vegetation, it can also increase the carbon-to-nitrogen ratio in plants. In one study, such fertilization of forage grasses for livestock increased their abundance but reduced their nutritional value, affecting livestock weight and performance (EPA 2009e). Although studies have shown that elevated CO_2 levels resulted in an increase in plants' carbon-to-nitrogen ratio, one experiment found that higher levels actually triggered enhanced photosynthetic nitrogen use efficiency[75] in C_3 plants, which was predominantly caused by improved CO_2 uptake (Leakey et al. 2009).

Additionally, some evidence suggests that long-term exposure to elevated ambient CO_2 levels, such as areas near volcano outgassing, will result in a die-off of some plants. Although, under typical atmospheric CO_2 concentrations, soil gas is 0.2 to 0.4 percent CO_2, in areas of observed die-off, CO_2 concentrations comprised as much as 20 to 95 percent of soil gas (EPA 2009e). Any CO_2 concentration above 5 percent is likely to adversely impact vegetation, and if concentrations reach 20 percent, CO_2 is observed to have a phytotoxic[76] effect (EPA 2009e).

The current annual exchange in CO_2 between the atmosphere and terrestrial ecosystems is estimated at 9 to 10 times greater than annual emissions produced as a result of burning fossil fuels. Even a small shift in the magnitude of this exchange could have a measurable impact on atmospheric CO_2 concentration (Heath et al. 2005). The aboveground/belowground processes and components in terrestrial ecosystems typically sequester carbon.

Recent studies have confirmed that variations in atmospheric CO_2 have impacts not only on the aboveground plant components, but also on the belowground microbial components of these systems. Experiments have shown that elevated CO_2 levels cause an increase in belowground

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[74] C_3 and C_4 plants are differentiated by the manner through which they use CO_2 for photosynthesis, lending explanation to the differences in plant yield under similar ambient CO_2 conditions.
[75] "Photosynthetic nitrogen efficiency" is the amount of carbon in the plant that is converted to usable sugars during photosynthesis. With greater atmospheric CO_2, the amount of carbon converted to sugars is greater even when the amount of nitrogen is available to the plant does not change.
[76] Phytotoxicity is an abnormal adverse reaction of a plant to ultraviolet radiation.

net primary production and fine-root biomass (Pritchard 2011; Jackson et al. 2009 citing Fitter et al. 1995, Hungate et al.1997, Matamala and Schlesinger 2000, King et al. 2001, Norby et al. 2004, and Finzi et al. 2007) with one study showing a 24 percent increase of fine-root biomass in the top 15 centimeters (approximately 6 inches) of soil and a doubling of coarse-root biomass in elevated CO_2 (Jackson et al. 2009).

In one study, an increase in CO_2 directly resulted in increased soil microbial respiration due to faster outputs and inputs, observed through amplified photosynthesis (Jackson et al. 2009 citing Canadell et al. 1995, Luo et al. 1996, Bernhardt et al. 2006, Gill et al. 2006, Hoosbeek et al. 2007, Wan et al. 2007). After 4 to 5 years of increased exposure to CO_2, "the degree of stimulation declined" to only a 10- to 20-percent increase in respiration over the base rate (King et al. 2004). Additionally, the degree of stimulation was linked to variability in seasonal and interannual weather (King et al. 2004), with root biomass, soil respiration, and other variables found to typically peak in midsummer and lessen in winter (Jackson et al. 2009). Increased soil respiration and changes in other variables, such as productivity, alters the concentration of CO_2 in soil pore spaces, which impacts weathering of carbonates, silicates, and other soil minerals (Jackson et al. 2009 citing Sposito 1989, Andrews and Schlesinger 2001, Pendall et al. 2001, Karberg et al. 2005). Ryan et al. (2008) suggest that for forest ecosystems, several unresolved questions prevent a definitive assessment of the effect of elevated CO_2 on components of the carbon cycle other than carbon sequestration primarily in wood (EPA 2009e).

The increase in microbial respiration could, therefore, diminish the carbon sequestration role of terrestrial ecosystems. Because of the number of factors involved in determining soil respiration and carbon sequestration, the threshold for substantial changes in these activities varies spatially and temporally (King et al. 2004).

Elevated CO_2 levels were also found to change the functional structure of soil microbial communities, which could have significant impacts on soil carbon and nitrogen dynamics (He et al. 2010). More specifically, the study found that when CO_2 levels increased, genes involved in labile carbon degradation, carbon fixation, nitrogen fixation, and phosphorus release also increased. Furthermore, no significant changes were found in the quantity of genes associated in recalcitrant carbon degradation and CH_4 metabolism. Structural and functional alterations, such as these, could modify the way microbial ecosystems regulate changes in CO_2 concentrations (He et al. 2010). However, a 2011 study suggests that although increasing atmospheric CO_2 positively affects root growth, it might not have any significant effect on soil microbes, simply because the increase is dwarfed by the amount of carbon already available to microbes in soil pore space (Pritchard 2011).

Elevated CO_2 concentrations have physiological impacts on plants, which result in further climatic changes, a process referred to as "CO_2-physiological forcing" (Cao et al. 2010). Increased CO_2 levels cause plant stomata to open less widely, resulting in decreased plant transpiration. A reduction in canopy transpiration causes a decrease in evapotranspiration that triggers adjustments in water vapor, clouds, and surface radiative fluxes. These adjustments ultimately drive macro climatic changes in temperature and the water cycle (Cao et al. 2010). One study found that the physiological effects from a doubling of CO_2 on land plants resulted in a 0.42 plus or minus 0.02 Kelvin increase in air temperature over land and an 8.4 plus or minus 0.6 percent increase in global runoff (generally caused by reduced evapotranspiration). Furthermore, the study reported that a reduction in plant transpiration caused a decrease in relative humidity over land (Cao et al. 2010).

CHAPTER 6 LITERATURE SYNTHESIS OF LIFE-CYCLE ENVIRONMENTAL IMPACTS OF CERTAIN VEHICLE MATERIALS AND TECHNOLOGIES

6.1 Introduction

6.1.1 Purpose of Including a Literature Synthesis of Life-cycle Environmental Impacts of Certain Vehicle Materials and Technologies

NHTSA anticipates that, to meet the proposed standards, manufacturers will incorporate advanced technologies that allow vehicles to achieve increasing levels of fuel economy. As noted in public scoping comments and in comments to previous fuel economy rulemakings, the wider use of some of these technologies in automotive manufacturing could result in environmental impacts different from those associated with the use of more conventional automotive technologies. Commenters suggested that understanding the life-cycle implications of vehicles is important, particularly the upstream emissions associated with electricity generation for electric vehicles (EVs) and potential changes in types of materials used in an effort to reduce vehicle weight. Recognizing the potential importance of these impacts, NHTSA has performed a literature synthesis of studies that have analyzed the life-cycle environmental implications of producing certain materials and technologies the agency expects will be employed in the light-duty vehicle sector in the future.[1] While NHTSA recognizes that such an analysis is not required, it is helpful to the decisionmaker in the specific context of this rulemaking, where manufacturers could employ a suite of technology options, with different environmental impacts, in meeting the proposed standards.

A complete life-cycle assessment (LCA) of the impacts of the CAFE standards rulemaking, which is beyond the scope of this EIS, would include specific energy, emissions, and other environmental impact estimates associated with manufacturing the regulated vehicles, producing materials, and constructing facilities for producing and assembling vehicle components. Such an assessment would require extensive information on many variables that are highly uncertain, including the future behavior of automobile manufacturers in response to the proposed standards – what technologies they would apply to each future vehicle and how many vehicles they would manufacture. CAFE standards are performance-based rather than technology-mandating, so NHTSA does not and cannot require that manufacturers employ specific technologies to meet those standards. As a result, in setting CAFE standards, NHTSA does not attempt to predict precisely how each manufacturer will respond to the standards, because manufacturers may choose whatever technologies they wish to meet the proposed standards. NHTSA's analysis of technology application simply demonstrates one potential path to compliance for the industry. Thus, while NHTSA's analysis of the proposed standards is based on the best available information about what vehicles the agency expects manufacturers to build and what technologies they might apply to those vehicles to improve their fuel economy, we do not attempt to predict or analyze exactly how manufacturers will respond to the proposed standards. In the absence of any precise forecast about the specific technology choices of individual manufacturers, NHTSA is providing a literature synthesis to help decisionmakers understand some of the life-cycle implications associated with some of the most prominent

[1] By including this chapter on LCA in this EIS, NHTSA does not mean to imply that vehicle manufacturers should be held responsible for the environmental impacts that accrue at every stage of a vehicle's life-cycle. Again, the impacts are simply included here to inform the decisionmakers about certain broader environmental implications of the rulemaking action.

emerging materials, technologies, and systems the agency expects will be employed in the future in the light-duty vehicle sector. As described in the following sections, the literature synthesis is meant to qualitatively assess the life-cycle environmental impacts of materials and technologies but due to heterogeneity of the results it is not to be used as a basis for decision-making.

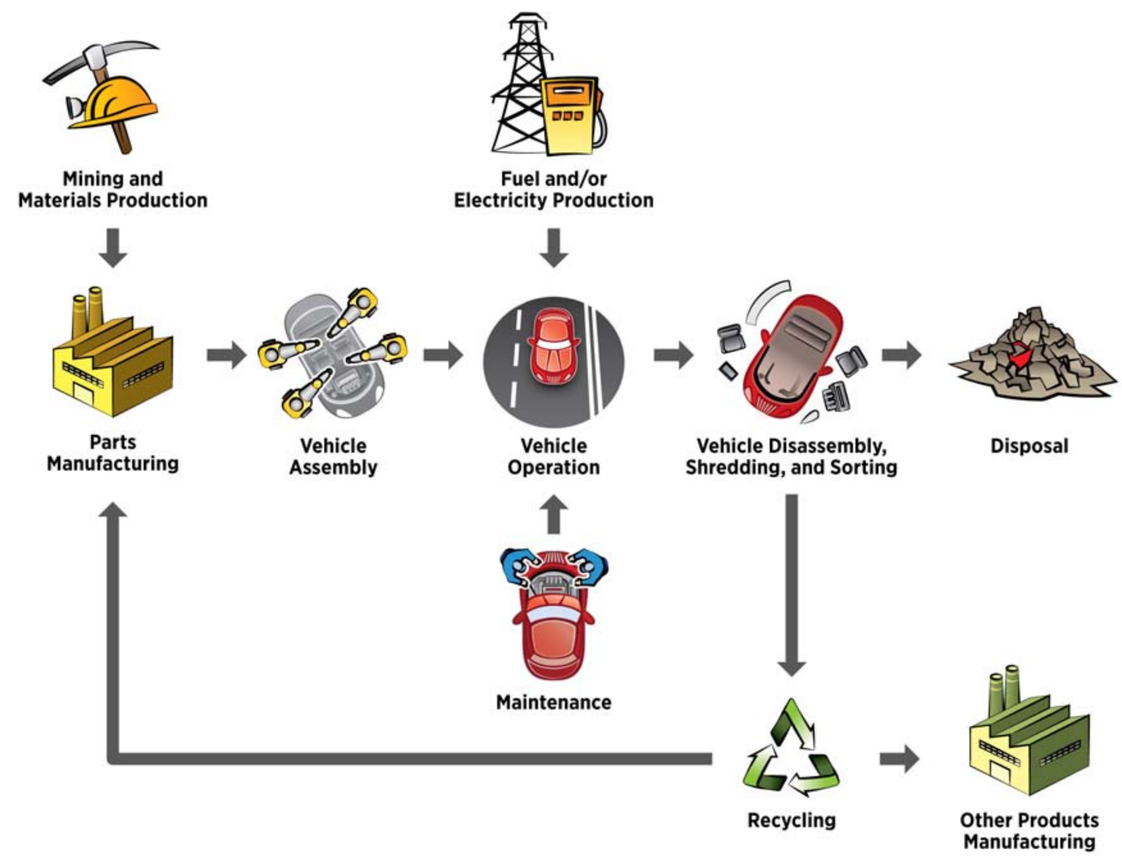
6.1.2 Overview of Life-cycle Assessment in the Vehicle Context

LCA is an analytical method based on a systems perspective used to evaluate the environmental impacts of materials, products, processes, or systems throughout their life cycles. A systems perspective offers a holistic way to identify, view, assess, and solve environmental problems that takes into account interactions between industrial and natural systems (Garner and Keoleian 1995). The International Organization for Standardization (ISO), the leading standards-setting organization that provides guidance on developing and reporting LCAs, defines LCA as the "compilation and evaluation of the input, output, and potential environmental impact of a product system throughout its life cycle" (ISO 2006). The literature synthesis for this EIS focuses on existing LCAs that evaluate the life-cycle impacts of certain vehicle technologies, materials, and systems NHTSA expects to be used to improve fuel economy in light-duty vehicles during the years covered by the proposed rule. By looking at the environmental impacts of the entire life cycle of a vehicle, rather than only its use (i.e., driving), LCA allows a holistic evaluation of vehicle technologies.

Like any product, a vehicle's environmental impacts do not accrue exclusively during the time it spends on the production line. Activities at each stage of a vehicle's life cycle contribute to emissions of GHGs, energy use, and other environmental impacts. For example, mining and transporting ore requires energy (usually in the form of fossil fuels), as does transforming ore into metal, shaping the metal into parts, assembling the vehicle, driving and maintaining the vehicle, and disposing of and/or recycling the vehicle at the end of its life. Recycling vehicle components can save energy and resources and can reduce emissions by displacing the virgin production of materials, but even recycling requires energy and produces emissions. Vehicle LCAs typically evaluate environmental impacts associated with five primary stages: raw-material extraction, manufacturing, vehicle use, end-of-life management, and transportation between these various stages. Raw-material extraction includes the mining and sourcing of material and fuel inputs. The manufacturing stage often consists of substages, including material and part production and vehicle assembly. The use stage is typically comprised of two substages: the driving substage (e.g., gasoline production and combustion) and the maintenance substage (e.g., part repair or replacement). End-of-life management can include such steps as parts recovery, disassembly, shredding, recycling, and landfilling. Figure 6.1.2-1 provides a diagram of the vehicle life cycle.

Changes in vehicle design and materials can impact the energy use and associated GHG emissions and other environmental impacts at various stages of the vehicle life cycle. For example, materials and technology substitutions can result in less energy consumption during the vehicle use phase. However, obtaining the components and manufacturing the materials can be energy intensive. Because LCA examines multiple life-cycle stages, an LCA study can help determine whether certain materials and technologies save energy over the vehicles' entire life cycles, keeping all other factors (e.g., vehicle life and weight) equal. Changes in the material composition of vehicles could decrease the global warming potential (GWP) of the use stage, but could increase that of the raw-material extraction stage (Geyer 2008). On the other hand, because of the length of vehicle lifetimes, the fuel-saving benefits realized during a vehicle's use stage due to improved fuel economy could very likely outweigh the additional energy investment associated with material changes (Cheah et al. 2009).

Figure 6.1.2-1. Vehicle Life Cycle



As these examples illustrate, LCA allows users to evaluate the environmental impacts of using different vehicle technologies on an equal basis within a given study. However, LCAs vary greatly in their scope, design, data sources, and assumptions, making it challenging to compare results between studies. In setting the scope of each study, LCA practitioners decide on the unit of measure, life-cycle boundaries, and environmental impact categories to consider, among other factors that address the defined purpose of the study. For example, the use of different functional units (i.e., the basis to measure the results across different materials and technologies) varies among studies. Most studies in this literature synthesis evaluate different types of passenger cars with different assumptions for car weight, vehicle life, and miles traveled underlying the functional unit. In terms of impacts, some studies include those across the entire cradle-to-grave life-cycle (i.e., from resource extraction through end of life), including impacts from extraction of all energy inputs in addition to materials. Others include impacts only from cradle to gate (i.e., from prior to vehicle use, but excluding end-of-life). Most of the studies in this literature synthesis evaluated energy use and climate change impact measured by GHG emissions, but several also included other environmental impact categories (e.g., acidification, eutrophication, odor and aesthetics, water quality, landfill space, ozone depletion, particulates, solid and hazardous waste generation, and smog formation). Data availability often influences the boundaries and impacts included.

LCA practitioners also use different approaches. Some perform bottom-up analyses (e.g., Khanna and Bakshi 2009) using data at the unit process level (i.e., the smallest sub-stage for which input and output data are quantified in a life-cycle inventory); others perform a top-down analysis using economic data (e.g., Lloyd and Lave 2003); still others use a hybrid LCA approach. Most LCAs considered for purposes of this EIS follow an *attributional* LCA approach that evaluates impacts associated with the physical flows (inputs and outputs) relevant to the specific material or technology being analyzed. In contrast, *consequential* LCAs estimate the environmental impacts influenced by product system change; such studies require broader system boundaries. In establishing the system boundaries, when several products are produced from a system, LCA practitioners also must decide how to assign or allocate environmental impacts between the functional unit (i.e., the product under study) and other co-products produced by the system.[2] For example, scrap materials can be used for other, secondary purposes outside the vehicle life cycle. Studies that consider scrap flows outside the vehicle life-cycle boundary might (1) allocate a portion of the impacts associated with vehicle manufacture or recycling to the scrap flow, (2) treat scrap as a waste flow and not allocate any impacts to it, or (3) expand the system to include the scrap output flow within the system boundary. The varying treatment of scrap material and other LCA aspects and assumptions in each study does limit the comparability of the results.

Because LCAs are highly sensitive to design and input assumptions, such analyses are subject to variation in calculated impacts and associated conclusions. Generally, however, based on the studies considered for this synthesis, it appears that most energy is consumed and most GHGs are emitted during the vehicle use stage. This stage is estimated to account for approximately 80 percent of the life-cycle vehicle GHG emissions in conventional internal combustion engine vehicles (Hakamada et al. 2007). The manufacturing stage is the second most energy- and GHG-emission- intensive LCA stage (Hakamada et al. 2007). This stage can account for 5 to 15 percent of total vehicle life-cycle GHG emissions (Geyer 2008, Hakamada et al. 2007). As manufacturers strive to improve fuel economy (in response to regulatory requirements and other factors), vehicle emissions associated with the use stage are expected to decrease as a percentage of overall life-cycle emissions.

6.1.3 Scope of Literature Synthesis of Life-cycle Environmental Impacts of Certain Vehicle Materials and Technologies

NHTSA performed a comprehensive literature synthesis to find and synthesize studies that assess the implications and environmental effects of emerging materials and technologies associated with improving fuel economy in the light-duty vehicle sector using a life-cycle perspective.

Materials and technologies of particular interest included aluminum, high-strength steel, and battery technologies associated with EVs. Most studies identified focus mainly on the life-cycle energy and climate change impacts (i.e., as characterized by GHG emissions, which is sometimes referred to as GWP), although other environmental implications (e.g., air quality impacts) also are addressed to a lesser extent in the literature.

[2] ISO advises that LCAs avoid allocation by dividing the process into separate production systems or through system expansion, including the additional co-product functions (ISO 2006).

The approach to developing the literature synthesis involved the following steps:

- Establishing the scope for the review
- Researching, gathering, and identifying academic, peer-reviewed studies
- Developing a tailored literature review matrix spreadsheet to compile, track, and compare different key elements
- Evaluating results and synthesizing findings

NHTSA performed research to identify studies across a range of sources, including academic journals and industry association and non-governmental organization publications. In addition, NHTSA performed an electronic search using DIALOG – an online literature service that aggregates 530 databases covering a range of disciplines into one searchable source. This literature synthesis identified 50 studies that represent the perspectives of various stakeholders, including industry, government, and non-governmental organizations.

In addition, NHTSA contacted stakeholders developing this research, as identified through the literature search, at Argonne National Laboratory, the Massachusetts Institute of Technology Materials Systems Laboratory, the University of Michigan, the University of California at Davis, and the International Institute for Clean Transportation. The stakeholders contacted provided feedback on additional relevant studies to include as part of the literature synthesis.

Appendix D lists all of the studies reviewed. Most of the studies identified were published within the last 10 years. For each study reviewed, NHTSA tracked various elements included in the study. These included information on the geographic applicability of the study, the technologies or materials discussed, the scope of the LCA boundaries (e.g., cradle to gate) and the environmental impacts quantified. NHTSA also gathered general study information (e.g., study purpose, reference year, and overarching assumptions). Table 6.1.3-1 describes the key elements tracked in the literature synthesis.

Table 6.1.3-1. Key Elements Tracked in the Literature Synthesis

General Elements	LCA Elements
Publication date	Geographic applicability
Study-wide assumptions	Technologies or materials
Purpose	Scope of LCA boundaries
Study type	Environmental impacts
Peer reviewed	Limitations and items of particular note

6.2 Emerging Materials and Technologies

Emerging developments in technology and vehicle design offer the potential for increased vehicle fuel economy and reduced environmental impacts during the rulemaking time frame and beyond. Trends addressed in this literature synthesis include mass reduction through material substitution (including aluminum, high-strength steel, polymer composites, magnesium, and titanium), and EV technologies.

Aluminum, which is currently used most intensively in the packaging and transportation sectors and can be used as a replacement for conventional (mild) steel, combines a high strength-to-weight ratio, corrosion resistance, and processability (Cheah et al. 2009).

High-strength steel has the same density as conventional steel, but provides greater strength, such that less high-strength steel is required than conventional steel to fulfill the same function. Consequently, high-strength steel provides the greatest weight-reduction benefits when used in structural or load-bearing applications, rather than non-load bearing uses, where strength is less of a factor in material use (Kim et al. 2010b).

Polymer-based composites, including nano-based technologies, have also received increasing attention as an alternative to other materials (e.g., mild steel and aluminum) used in transportation and other sectors. These materials can offer enhanced properties, such as high strength-to-weight ratios, thermal and flame resistance, enhanced barriers that reduce or eliminate gas permeation, and corrosion resistance (Khanna & Bakshi 2009).

Magnesium is a very lightweight metal that is already used in a limited way for mass reduction in vehicles – current on-road vehicles use approximately 11 pounds per vehicle, on average (Cheah 2010). Magnesium is more expensive and energy intensive to produce than the mild steel that it replaces, but offers significant fuel economy improvements due to a 60 percent weight reduction.

Titanium is denser than magnesium, but provides the highest strength-to-weight ratio of all metals. It can also offer significant fuel economy savings, but is extremely costly.

EVs have the potential to significantly reduce life-cycle environmental impacts compared to conventional vehicles. This literature synthesis focuses specifically on two primary determinants of EV life-cycle emissions: emerging battery technologies being employed in EVs and the upstream electricity generation grid mix associated with charging EVs. While nickel-metal-hydride batteries are currently used in hybrid vehicles, nickel-metal-hydride battery energy density is insufficient for full EVs (Boncort 2011). Batteries that employ lithium chemistries offer higher energy density. Lithium-ion batteries are therefore currently being used to power some plug-in hybrid electric vehicles (PHEVs) and full EVs (Boncourt 2011). It is also anticipated that EVs will continue to use lithium-ion (Li-ion) battery chemistries in the near future (NRC 2011). Because of the future potential of Li-ion batteries, the literature synthesis focuses primarily on batteries using Li-ion based chemistries.

6.2.1 Mass Reduction by Material Substitution

Mass reduction reduces fuel consumption by lowering vehicle mass while maintaining the same vehicle size. It can be achieved by removing or reducing the mass of vehicle components or by replacing heavier materials with lighter-weight materials without compromising strength and rigidity of components.

Reducing vehicle mass has implications across the life cycle of a vehicle. The potential impacts of mass reduction include reducing the amount of conventional material required to manufacture vehicles; increasing the amount of alternative, lighter-weight materials used to manufacture vehicles; saving fuel over the life of the vehicle; and influencing disassembly and recycling at end of life.

This section summarizes literature related to vehicle mass reduction with a focus on material substitution. Replacing conventional materials such as mild steel with other lightweight material reduces vehicle fuel consumption, but also could increase the upstream environmental burden associated with producing these materials. This section focuses on three primary material categories: aluminum and high-strength steel, polymer composites, and magnesium and other components. Sections 6.2.1.1 through 6.2.1.3 describe the materials, summarize the relevant literature, and identify important limitations across the studies reviewed.

6.2.1.1 Aluminum and High-strength Steel

Aluminum and high-strength steel can be used to provide similar levels of strength and rigidity as mild steel, while being lighter and using less material, respectively. Aluminum is a suitable substitute for cast-iron components and stamped-steel body panels, while high-strength steel is suited for replacement of structural steel parts (Cheah and Heywood 2011).

Eleven studies[3] in the literature synthesis examine or discuss the life-cycle environmental impacts of substituting aluminum and/or high-strength steel for mild steel components in vehicles (Kim et al. 2010a, Hakamada et al. 2007, Bertram et al. 2009, Dubreuil et al. 2010, Cáceres 2009, Stodolsky et al. 1995, Lloyd and Lave 2003, Geyer 2008, Birat et al. 2003, Weiss et al. 2000, Bandivadekar et al. 2008). Some of these (Bertram et al. 2009, Geyer 2008, Lloyd and Lave 2003, and Hakamada et al. 2007) focus on material substitution in specific vehicle components, whereas others (Weiss et al. 2000, Bandivadekar et al. 2008, and Kim et al. 2010a) estimated overall mass reduction from material substitution and vehicle redesign. The feasible amount of mass reduction is discussed in Chapter 3 of the Joint Technical Support Document. The studies show the following trends, which are discussed in more detail below:

- In general, the life-cycle analyses reported in the studies reviewed show that, across the entire vehicle life cycle, reductions in energy use and GHG emissions during the use stage of vehicles due to aluminum and high-strength steel material substitution exceed the increased energy use and GHG emissions needed to manufacture these lightweight materials at the vehicle production stage.
- However, the magnitude of life-cycle GHG-emission and energy-use savings are influenced by the amount of recycled material used in automobile components, the materials recycling rate at end-of-life, and – in the case of lightweighting through aluminum substitution – the location of aluminum production.

Aluminum and high-strength steel vehicle component production requires more energy and leads to higher GHG emissions compared to the production of mild-steel vehicle components due to the high energy requirement for new ingot production from mined ores (Bertram et al. 2009 and Hakamada et al. 2007). However, substituting aluminum and high-strength steel vehicle components for comparable mild-steel components can lead to a reduction in total vehicle weight and an increase in fuel efficiency during the use stage. Studies have found that, over the total vehicle life-cycle, the energy savings and reduced GHG emissions from this increase in fuel efficiency exceed the increased energy use and GHG emissions from aluminum production, resulting in an overall reduction in total life-cycle energy use and as much as a 5.3 percent decrease in total life-cycle GHG emissions (Bertram et al. 2009, Hakamada et al. 2007, Stodolsky et al. 1995). For example, the increased energy (i.e., fossil fuels and electricity) and GHG emissions associated with producing the aluminum parts substituted for mild steel front-end parts of a GM-Cadillac CTS were offset by use-stage savings after the first 35,000 kilometers (21,748 miles) of travel (Dubreuil et al. 2010). A separate study found that a 23

[3] The following studies in this literature review indicated that they relied – at least partially – on industry funding or industry-funded data to evaluate the life-cycle impacts of aluminum and high-strength steel material substitution: Kim et al. (2010a), Geyer (2007, 2008), Dubreuil (2010), Birat et al. (2003). All of the studies reviewed have undergone peer review for publication in academic journals. Certain studies noted where critical reviews were conducted in accordance with ISO 14044 standards on either the methodology (Geyer 2008) or life-cycle inventory inputs (Dubreuil 2010), or where critical review was not performed (Bertram et al. 2009).

percent reduction in total vehicle mass through material substitution with aluminum decreased life-cycle GHG emissions by approximately 29,000 pounds of carbon dioxide (CO_2) compared to a baseline vehicle, and a 19 percent mass reduction through high-strength steel material substitution reduced life-cycle GHG emissions by approximately 27,600 pounds of CO_2 (Kim et al. 2010a)

On a fleetwide scale, substituting aluminum for steel in body panels in 1 year's sales volume of vehicles in the United States in 2000 (16.9 million vehicles) would, according to one study, have led to a decrease in 3.8 million tons of GHGs over the life cycle of the vehicles (Lloyd and Lave 2003). One study that included vehicle-level and fleet-level comparisons of aluminum substitution for mild-steel and castiron components showed that the additional CO_2 emissions that resulted from the production of aluminum for aluminum castings were offset by fuel savings after 2 to 3 years of vehicle use, and CO_2 emissions from aluminum beams and panels were offset in 4 to 7 years of vehicle use (Cáceres 2009).

It is important to note that many studies emphasized the sensitivity of LCA results to the amount of recycled material used in automobile components and the materials recycling rate at end of life. Substituting rolled aluminum or high-strength steel for mild-steel sheet in vehicles reduces life-cycle GHG emissions, but the savings from aluminum results can depend on scrap recycling rather than just vehicle fuel economy improvement (Geyer 2008). Life-cycle GHG savings from aluminum vehicle component substitution also depend heavily on the location of aluminum production and the share of secondary aluminum used (Kim et al. 2010a). Several studies found that GHG emissions savings from vehicles using lightweight materials in relation to the baseline might or might not depend on the materials recycling rates achieved, with estimates ranging from lower life-cycle GHG emissions only under scenarios with "very high recycling levels" for aluminum components, to significantly lower life-cycle GHG emissions compared to comparable mild-steel components, even with a "non-realistic" recycling rate of 0 percent (Bertram et al. 2009, Birat et al. 2003).

6.2.1.2 Polymer Composites

Various types of reinforced polymer composites are in use or in development as substitutes for mild steel or aluminum, predominantly in vehicle body panels. These materials offer added tensile strength and weight reduction potential compared with mild steel[4] and include glass- and carbon-fiber-reinforced polymer composites and nanocomposites, such as those reinforced with nanoclays or carbon nanotubes (Lloyd and Lave 2003, Cheah 2010). At the nano scale, carbon fibers offer additional tensile strength and provide other functionalities such as electrical conductivity and antistatic properties, which are useful properties for automobile components such as body panels and casings for electronic equipment (Khanna and Bakshi 2009).

Seven studies in the literature synthesis examine or discuss the life-cycle environmental impacts of substituting reinforced polymers or composites for aluminum or mild-steel components in vehicles (Lloyd and Lave 2003, Khanna and Bakshi 2009, Cheah 2010, Overly et al. 2002, Gibson 2000, Weiss et al. 2000, Sullivan et al. 2010). Two of these studies (Lloyd and Lave 2003 and Khanna and Bakshi 2009) focus on applications based on nanotechnology.

[4] Estimates of the weight reduction in automobile body parts range from 38 to 67 percent (Overly et al. 2002, Cheah 2010, Lloyd and Lave 2003, Khanna and Bakshi 2009).

The studies show the following trends, which are discussed in more detail below:

- Polymer composites (including those reinforced with glass, carbon fiber, or nanoclays) used in vehicle body panels are more energy and GHG intensive to produce compared to mild steel (but less than aluminum).
- When considering the full life cycle of the vehicle, the use of polymer composites in vehicle body panels leads to reduced energy use and GHGs emitted. This reduction is a result of the significant reductions in vehicle weight and the subsequent improvements in fuel economy.
- When considering other environmental impact categories (e.g., acidification, water use, water quality, landfill space), these polymer composite materials also result in overall lower life-cycle impacts compared to mild steel, and in most cases, compared to aluminum.
- Certain aspects (e.g., end-of-life assumptions) deserve additional analysis in future studies.

Several studies show that the upstream extraction, materials processing, and manufacturing stages for carbon-fiber- and glass-fiber-reinforced composites used in vehicles are more energy and GHG intensive than those for conventional (mild) steel, but less than those for aluminum (Overly et al. 2002,[5] Cheah 2010, Weiss et al. 2000, Gibson 2000, Khanna and Bakshi 2009). For example, estimates of the cradle-to-gate[6] energy required for carbon nanofiber polymer composites range from nearly 2 to 12 times greater than the energy requirements for steel[7] (Khanna and Bakshi 2009). According to one study, in relation to aluminum used in automobile bodies, polymer composites require less primary energy and are associated with lower GHG emissions;[8] however, if *recycled* aluminum is used, the energy requirements and upstream GHGs are comparable to that of polymer composites (Weiss et al. 2000).

While polymer composites used in vehicle body panels are more energy and GHG intensive to produce compared to mild steel, inclusion of the product use phase results in net life-cycle energy savings and reduced GHGs. This "cross-over" occurs sometime during the lifetime of the vehicle (Gibson 2000). One study estimates that substitution of a high-performance clay-polypropylene nanocomposite for steel in a light-duty vehicle could reduce life-cycle GHG emissions by as much as 8.5 percent, and that GHG emissions associated with material production of that high-performance material are 380 times smaller than those associated with vehicle use[9] (Lloyd and Lave 2003). This energy and GHG reduction is a result of the significant reductions in vehicle weight and the subsequent improvements in fuel economy.

In general, the studies that look at multiple environmental impact categories conclude that these lightweight composite materials offer overall environmental benefits compared to mild steel – and in most cases, compared to aluminum – across the vehicle life cycle. Carbon-fiber-reinforced polymer composite used in vehicle closure panels[10] show lower environmental impacts compared to steel, aluminum, and glass-fiber-reinforced polymer composite in most impact categories – including nonrenewable and renewable resource use, energy use, global

[5] Note that Overly et al. (2002) include extraction and material processing, but not manufacturing, in the study scope due to data limitations, but note that the impacts are typically the smallest during this stage.
[6] Including carbon nanofiber production, polymer resin production, carbon nanofiber dispersion, and composite manufacture; excluding vehicle use and associated gasoline production and the end-of-life stages.
[7] Standard steel plate used in this study.
[8] This upstream energy and GHG impact for a plastic automobile body is approximately about one-third of that of one with virgin aluminum components (Weiss et al. 2000).
[9] Including petroleum production, which refers to the upstream emissions associated with producing the petroleum that the vehicles consume.
[10] Includes four door panels, the hood, and the deck lid.

warming potential, acidification, odor/aesthetics, water quality (biochemical oxygen demand), and landfill space (Overly et al. 2002). Applications of glass-reinforced-polymer composites result in the lowest environmental impacts in ozone depletion and particulate matter formation (Overly et al. 2002). Other studies note additional carbon composite benefits in air emissions, water emissions, and hydrogen fluoride emissions over the entire vehicle life cycle compared to mild steel and aluminum (Gibson 2000). A clay-polypropylene nanocomposite substituted for steel shows reduced life-cycle environmental impacts across all impact categories (including electricity use, energy use, fuel use, ore use, water use, conventional pollutants released, global warming potential, and toxic releases and transfers), except for a slight increase for hazardous waste generation (Lloyd and Lave 2003). The lower impacts are largely because the vehicle production requires less material with the lighter material. When carbon-fiber-reinforced polymer replaces a much larger share of the steel in the vehicle body panel (i.e., beyond the closure panels), the environmental benefits of carbon fiber lessen (Overly et al. 2002).

Studies acknowledge that large uncertainties underlie the results and that certain assumptions have a significant influence on the results. For example, consideration of fleet effects, such as upstream production energy mix (e.g., the high share of hydropower used in the production of aluminum), could change the results (Lloyd and Lave 2003). Studies handled the impacts from end of life in different ways – e.g., assuming composites were landfilled at end of life (Overly et al. 2002) or excluded the impacts altogether (Khanna and Bakshi 2009). Studies noted that a more complete analysis would look at impacts associated with recycling of composites and the effect of using recycled versus virgin material inputs in their production (Lloyd and Lave 2003, Weiss et al. 2000) and consider reparability (Lloyd and Lave 2003, Overly et al. 2002). If composite-based vehicle panels are more difficult to repair and therefore need to be discarded more frequently or earlier in the vehicle's life cycle and repeatedly replaced, the environmental benefits could be diminished. It is important to note that the composite and nanotechnologies are rapidly developing and evolving. To reflect some of the current variations, studies evaluated different types of materials, including lower and higher performance materials. However, the environmental impacts are expected to change as material design advances and processes evolve.

6.2.1.3 Magnesium and Titanium

Magnesium is an abundant metal with a density approximately one-fifth that of steel and approximately 60 percent that of aluminum. At present, on average, magnesium content per vehicle is approximately 5 kilograms (11 pounds), but it is estimated that this average content will double to approximately 10 kilograms (22 pounds) by 2020 (Cheah 2010). Magnesium-substituted vehicles have higher fuel efficiencies than conventional and aluminum-substituted vehicles due to lighter vehicle weights from magnesium's low density (Hakamada, et al. 2007, Cáceres 2009). On average, magnesium provides a 60 percent weight reduction over steel and 20 percent over aluminum, with equal stiffness (Cheah 2010).

Eight studies in the literature synthesis examined the life-cycle environmental impacts of substituting magnesium and/or titanium for steel and aluminum components in vehicles (Hakamada et al. 2007, Dubreuil et al. 2010, Cheah 2010, Tharumarajah and Koltun 2007, Dhingra et al. 2000, Sivertsen et al. 2003, Cáceres 2009, Gibson, 2000). However, only two of the studies examined titanium (Dhingra et al. 2000 and Gibson 2000). Dhingra et al. (2000) only included titanium as part of the collective impact of several simultaneous mass reduction strategies in one vehicle, so it was not possible to draw any firm conclusions about the use of titanium for mass reduction.

Magnesium can be produced from the salt magnesium chloride using electrolysis or from ore (mainly dolomite) using the Pidgeon process, which involves reducing magnesium oxide at high temperatures with silicon. The Pidgeon process is used mainly in China (Dubreuil et al. 2010). In general, magnesium is more expensive and energy intensive to produce than steel. Titanium is also abundant in nature, but is particularly difficult and expensive to produce in its metallic form. Titanium is denser than magnesium or aluminum, but has a higher strength-to-weight ratio than steel, aluminum, or magnesium, meaning that using less of it will achieve equivalent strength.

Overall, the studies reviewed show the following trends:[11]

- Magnesium and titanium are more energy and GHG intensive to produce than steel or aluminum.
- Significant reductions in vehicle weight and GHG emissions can be achieved in the future by substituting magnesium and titanium for heavier components currently in use. However, break-even distances (the driving distance at which fuel economy savings outweigh increased production energy) can be relatively high in relation to other materials. For example, examining only mass reduction of the engine block, use of coal-based Pidgeon process magnesium could result in a break-even distance of between 20,000 kilometers and 236,000 kilometers (12,500 miles and 147,000 miles) compared to other materials ranging from iron to aluminum produced from different production processes and locations (Tharumarajah and Koltun 2007). The use of coal-based Pidgeon process magnesium decreases the life-cycle energy and GHG benefits of magnesium. The more GHG-intensive Pidgeon process magnesium is used, the longer the break-even distance becomes (Cáceres 2009).
- If a large proportion of recycled magnesium is used, the production energy and GHG disadvantages of using magnesium can be significantly offset (Hakamada et al. 2007). Generally, the higher the proportion of recycled magnesium, the shorter the break-even distance.
- Several of the studies looked at the effects of replacing particular automotive parts. Given the heterogeneity of the studies, it is difficult to make conclusive statements, but which part of the automobile is substituted could make a difference to LCA results. In general, however, weight reduction is probably the primary consideration in use-phase GHG emissions, and which parts are replaced will be subject mostly to engineering considerations (Hakamada et al. 2007).

According to Gibson (2000), the life-cycle energy consumption of an automotive part manufactured from titanium is the highest of all materials analyzed in that study, including advanced automotive materials such as carbon-fiber-epoxy composite and conventional materials such as steel. This is due to the high energy use associated with titanium production, including extraction of titanium dioxide ore and subsequent oxidation of magnesium metal. In addition, GHG emissions and other air emissions, including sulfur oxide (SO_x), are highest for titanium as compared to other materials.

[11] Differences in scope and functional units (i.e., the reference unit against which environmental impacts are compared) across the studies limit their comparability with each other. For example, modeling different magnesium production processes and recycled contents has a great effect on the life-cycle emissions. Assumptions about which parts are replaced or supplemented with magnesium vary widely across studies, as do methodologies such as the weight-for-weight ratio at which magnesium is substituted for steel.

The LCA literature generally agrees that magnesium substituted in vehicles requires more energy to produce than conventional and aluminum-substituted vehicles, and therefore produces more GHGs during that stage (e.g., Dubreuil et al. 2010, Tharumarajah and Koltun, 2007). Both electrolysis and the Pidgeon process are energy intensive, although electrolysis is 3 to 5 times more energy efficient than the Pidgeon process (Cheah 2010). China produces approximately 80 percent of world magnesium, almost entirely using a coal-powered Pidgeon process, which leads to higher GHG emissions per unit of magnesium than magnesium produced using electrolysis, a process that is often powered by hydroelectricity or other lower-carbon energy sources (Dubreuil et al. 2010). In addition, three potent GHGs are used during primary metal production: sulfur hexafluoride and two perfluorocarbons (Dhingra et al. 2000). Sulfur dioxide is also used as a protective gas to cover molten magnesium during production (i.e., cover gas) (Dubreuil, et al. 2010).

Even considering the energy required to produce magnesium, several LCAs have found that, over vehicle life, the high fuel efficiency of magnesium-substituted vehicles lowers total energy use below that of conventional and aluminum-substituted vehicles. How much less energy is determined by which vehicle parts are substituted and methods used in manufacturing the magnesium. For titanium, even when considering the use stage of vehicles with a lifetime distance of 177,000 kilometers (109,983 miles) the higher production energy and environmental impacts associated with titanium material are larger than the avoided energy and environmental impacts associated with fuel consumption from the lighter weight vehicle.

The results of each LCA vary, depending on which component in the vehicle was substituted and manufacturing methods. Key assumptions that affect life-cycle environmental impacts associated with magnesium substitution include:

- Method of magnesium production – Assumptions about what proportion of magnesium comes from the Pidgeon process and what portion from electrolysis, as well as the assumed fuel sources, will have an effect on GHG emissions and energy use, because the Pidgeon process is more energy and GHG intensive.
- Sulfur hexafluoride (SF_6) – SF_6 is a potent GHG[12] and might be phased out of manufacturing in the near future in most countries. At present, SF_6 is used as a cover gas, (i.e., a protective gas to cover molten magnesium during production). To lower GHG emissions, SO_2 can also be used to treat magnesium, but it is toxic. Using SF_6 in manufacturing leads to a vehicle break-even point of approximately 200,000 kilometers (124,000 miles), while using SO_2 in manufacturing leads to a vehicle break-even point of approximately 67,000 kilometers (41,600 miles) (Sivertsen et al. 2003).
- Substitution characteristics – The weight-to-weight ratio at which one metal is substituted for another will affect LCA results, as will assumptions about metal stiffness and strength.
- Recycling – Magnesium is generally considered well suited to recycling. Approximately 5 percent of the energy used in production of virgin materials is needed for re-melting. Two types of materials are recycled: manufacturing scraps and post-consumer materials (Sivertsen et al. 2003). Because magnesium uses more energy to produce from virgin materials than to recycle, whether the material is recycled and at what rate, can have a great impact on LCA results.

[12] SF_6 has a GWP of 23,900.

6.2.2 Electric Vehicles

The term "electric vehicle" covers a range of different vehicle types, including battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs) (Notter et al. 2010, Patterson et al. 2011). EVs use battery technologies to provide power, therefore reducing or even eliminating liquid fuel consumption during vehicle operation. BEVs are purely electrically powered and do not incorporate an internal combustion engine. HEVs incorporate a battery and electric motor system coupled with an internal combustion engine and have on-board charging capabilities (e.g. regenerative breaking). PHEVs are fitted with a large capacity rechargeable battery that can also be charged from the electric grid; like HEVs, they also utilize an internal combustion engine as a backup when battery life is depleted.

This section discusses two important life-cycle issues associated with EVs: battery production and upstream electricity generation used to charge EVs.

6.2.2.1 Batteries

Most current HEVs use nickel-metal-hydride or sodium-nickel-chloride batteries, but the trend in the near future for all EVs is a shift toward Li-ion batteries (Majeau-Bettez et al. 2011, NRC 2011). The Li-ion battery is currently the preferred battery technology because of its electrochemical potential, lightweight properties, comparatively low maintenance requirements, and minimal self-discharge characteristics, which enables Li-ion batteries to stay charged for longer (Notter et al. 2010). There are different types of Li-ion batteries that vary by chemistry and cathode technology, including lithium-iron-phosphate, manganese-spinel (MS), nickel-cobalt-aluminum, and manganese-nickel-spinel, to name a few (Gaines et al. 2011). Each of these Li-ion battery types offers a different balance of performance and economic characteristics, including cost, specific energy, energy density, specific power, safety, and cycle life (Gaines et al. 2011, NRC 2011). Regarding material composition, Li-ion batteries consist mostly of heavy metals such as aluminum, steel, cobalt, gold, tin, and copper, as well as plastics (Notter et al. 2010). Lithium as a constituent in Li-ion batteries represents a small fraction (typically between 1 and 3 percent, depending on specific chemistry) of total battery composition (Gaines et al. 2011).

The most common process for extracting lithium is through extraction from lithium carbonate concentrations originally derived from brine-lake or salt-pan deposits (Gaines et al. 2011). One of the key environmental impacts from the lithium extraction industry is its impact on water use. Industrial facilities extracting lithium require the diversion of large quantities of water and are likely to return it to local ecosystems with higher concentrations of salts and other process chemicals, impacting local irrigation agriculture and regional biodiversity. Additionally, the evaporation ponds for the separation of lithium salts from liquids are lined with polyvinyl chloride (commonly called PVCs) and are a potential source of leachates (Hollender and Shultz 2010).

Several recent studies analyze the environmental impacts of Li-ion batteries across their life cycle and use in vehicles, including the impacts of upstream battery production. This literature synthesis indicated the following overarching trends of the environmental impacts associated with Li-ion battery production:

- The environmental impacts from Li-ion battery production, such as GWP and energy demand (i.e., fossil fuels and electricity), are a significant contributor to total BEV production-related environmental impacts. The inclusion of Li-ion batteries in BEV production causes the total environmental impacts associated with the production of a BEV to be larger than a conventional vehicle.

- However, across the full vehicle life cycle, including the use stage (i.e., operation), the environmental impacts associated with upstream battery production are small (less than 10 percent across most environmental impact categories).
- Compared to conventional vehicles, the additional environmental burdens associated with producing Li-ion batteries upstream is more than offset by the reduction in environmental impacts during the use stage for BEVs due to improved transport energy efficiency.
- Assuming similar vehicle life (e.g., 150,000 miles driven), the total vehicle life-cycle environmental impacts of an EV are less than a conventional vehicle.

Several studies have analyzed the environmental burdens associated with EV production, concluding that the upstream impacts of producing Li-ion batteries for EVs is significant, and that the production of EVs as greater environmental impacts compared to conventional vehicles. A study by Samaras et al. (2008) determined life-cycle GHG emissions of Li-ion batteries used in HEVs and PHEVs. The study analyzed the upstream energy and associated GHG emissions from raw-material extraction, battery production, and processing to determine the cradle-to-gate analysis of different sizes of Li-ion batteries, depending on the range of the EV. Notably, the impacts from battery end-of-life are omitted. The total energy required for upstream production is determined to be 1,700 megajoule of primary energy per kilowatt-hour of Li-ion battery capacity. Roughly 500 megajoule per kilowatt-hour is associated with raw-material extraction alone, so most of the primary energy requirement is associated with battery manufacture. Total GHG emissions associated with lithium battery production are approximately 120 kilograms (265 pounds) carbon dioxide equivalent (CO_2e) per kilowatt battery capacity.[13] Although the upstream production GHG emissions of Li-ion batteries are sensitive to assumptions about fuel mix for production and relative mix of virgin and recycled materials used in production, because of the additional GHG emissions associated with battery production, the total GHG emissions attributable to the production of an HEV or a PHEV are generally larger than those attributable to the production of a conventional vehicle (Samaras et al. 2008).

The environmental impacts of the battery production life-cycle stage itself are dominated by the production of the battery pack which includes the process energy for heating and roasting various components in the production of metals. However, within the framework of the assumed battery size (300 kilograms [approximately 660 pounds]) and vehicle life (150,000 miles), Notter et al. (2010) determined that the environmental impacts associated with the production of Li-ion batteries used in an EV are relatively small compared to the full life-cycle environmental impact of the vehicle.[14] The environmental impacts analyzed included abiotic depletion, nonrenewable cumulated energy demand, GWP, and Ecoindicator 99, which is a weighted average impact assessment score consisting of human health and ecosystem quality impact categories. Across the impact categories measured, the battery production share of total environmental impacts ranged between 7 (cumulated energy demand) and 15 percent (Ecoindicator99). The authors also note that the environmental impacts of the battery life cycle analyzed in their study are a worst-case scenario because no recycling benefits were assumed at end of life. According to the study, the natural resource savings for the battery life cycle could

[13] Assuming 75 percent of primary energy is fuel for electricity generation and the remainder (25 percent) is from diesel fuel combustion.

[14] The relatively minor environmental impacts of battery production are due to small weight of lithium content (0.007 kilograms per kilogram Li-ion battery) and low energy intensity of lithium extraction from brines. However, “If the lithium components were based on spodumene, a silicate of lithium and aluminum, the extraction of the lithium would require a considerable amount of process energy” (Notter et al. 2010, p. E).

be as high as 51 percent if a recycled content supply supplemented the virgin resource supply for Li-ion battery production.

As a comparative measure, in the context of the total vehicle life cycle environmental impacts of HEVs and PHEVs (i.e., including vehicle production, battery production, and use stage of vehicles), Samaras et al. (2008) concludes that GHG emissions associated with Li-ion battery materials and production account for only 2 to 5 percent of total life-cycle vehicle emissions.[15] This figure does account for GHG emissions impacts from battery and vehicle end of life because the authors determined that these stages were negligible across the full vehicle life cycle. The authors indicated that future research is needed to identify the environmental tradeoffs of other environmental impact categories in addition to climate change.

The cradle-to-gate GHG impacts associated with battery production (specifically lithium-iron-phosphate) calculated by Majeau-Bettez et al. (2011) (7 to 10 grams CO_2e per kilometer traveled) are comparable to Notter et. al (2010) (12 grams CO_2e per kilometer traveled) and Samaras et al. (2008) (7 to 10 grams CO_2e).[16] However, due to the sensitivity of assumptions about battery mass, life expectancy, and battery cycle life, the environmental impacts of batteries could be higher than documented (Majeau-Bettez et al. 2011). For Li-ion batteries produced and sourced in regions with a more carbon-intensive electricity grid mix, the life-cycle impacts of batteries increase significantly[17] (Majeau-Bettez et al. 2011). In terms of other environmental impacts, this study determined that most (30 to 50 percent) of the human toxicity and ecotoxicity impacts were associated with the copper used in the battery management system and the electrode constituents.

A paper by Gaines et al. (2011) focuses on the life-cycle energy implications of various types of Li-ion battery production for a PHEV with a nominal all-electric 20-mile range. Although GHG emissions are not calculated explicitly, Gaines et al. (2011) indicate that GHG emissions align closely with energy use. Recognizing the limitations of life-cycle data, particularly the lack of process-based data on lithium-constituent materials, Gaines et al. (2011) calculate that the energy associated with battery production accounts for only 2 percent of the total vehicle life-cycle energy use. As corroborated by other studies (e.g., Notter et al. 2010), the largest contributors to the battery production life-cycle energy profile include the constituent metals production (e.g., aluminum, steel, and cobalt) and the production and assembly of the battery pack itself.[18] There is potential to reduce the life-cycle energy implications (and therefore the associated GHG emissions) through recycling of battery components at end of life. Gaines et al. (2011) determined through scenario analysis that recycling heavy metals, including aluminum, steel, nickel, and copper, and other battery components, could reduce energy consumption of batteries by 30 percent compared to a base-case scenario of no recycling.

Although studies agree that the environmental impacts of the upstream production of an EV are higher than a conventional vehicle, the impacts associated with the production of Li-ion batteries are small in the context of the total vehicle life cycle. In addition, accounting for the vehicle's

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[15] The energy intensity of producing nickel-metal-hydride batteries is double that of Li-ion batteries, so adoption of nickel-metal-hydride batteries would increase battery impacts to 3 to 10 percent of life-cycle GHG impacts from PHEVs.
[16] To provide this comparison, Majeau-Bettez et al. (2011) convert their results, which are based on the functional unit of 50 megajoule energy delivered from the battery to the powertrain, into a distance-based functional unit (i.e., emissions per distance traveled) assuming a powertrain efficiency of 0.5 megajoule per kilometer traveled.
[17] Using average Chinese electricity grid mix during the production of Li-ion batteries to replace the average European electricity grid mix, life-cycle impacts of battery production would increase by 10 to 16 percent for GWP impacts and 10 to 29 percent for particulate matter and photochemical oxidant formation (Majeau-Bettez et al. 2011).
[18] Assuming a 160,000-mile life and no battery replacement.

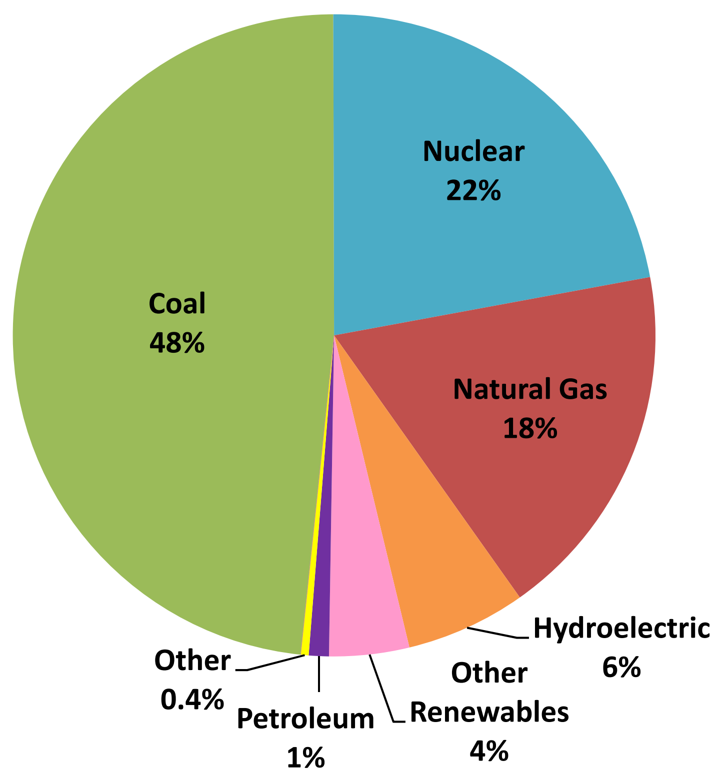
use stage time, it is clear that the environmental impacts of EVs are less than conventional vehicles (Notter et al. 2010, Samaras et al. 2008). However, as discussed in the next section, the environmental impacts of the use stage of EVs is highly dependent on the energy sources used for electricity production.

6.2.2.2 Electricity Associated with the Operation of Electric Vehicles

EVs, unlike conventional vehicles, have the potential for reduced (or zero in the case of "pure" EVs) tailpipe emissions. However, for EVs, the emissions associated with their mobility are shifted mostly upstream to the electric power grid. An accounting of the full life-cycle environmental impacts of EVs therefore includes the upstream impacts from generating the electricity (fuel) used as the source for the mobility energy.

Similar to conventional vehicles that use liquid fuels, most of the energy use and associated environmental impacts occur during the operation or use stage of an EV throughout its life (Samaras et al. 2008, Gaines et al. 2011, Notter et al. 2010). However, a 2010 study by the National Research Council and several partners indicates that the process of calculating the energy use and emissions associated with EVs is more complex than a similar calculation for conventional vehicles because the associated impacts depend strongly on how and where the electricity is generated (National Academy of Engineering & National Research Council 2010). Emissions and other environmental impacts from electricity production depend on the efficiency of the power plant and the mix of fuel sources used, also referred to as the "grid mix." In the United States, the grid mix is comprised of coal, nuclear, natural gas, hydroelectric, oil, and renewable energy sources (Figure 6.2.2-1).

Figure 6.2.2-1. U.S. Electric Power Industry Net Generation by Fuel, 2010[a]



a. EIA 2011d

This section focuses on the environmental impacts associated with upstream electricity production used to charge EVs and power them during operation.

Based on this literature synthesis, the following trends are highlighted:

- Life-cycle GHG emissions (and most other environmental impacts) on a per-mile-traveled basis across different types of EVs (e.g., hybrids, BEVs, and PHEVs) are dominated by the use stage (e.g., the impacts associated with electricity generation upstream).
- There is a potential for EVs to significantly reduce petroleum energy use, as well as GHG emissions and other environmental impacts associated with reduced petroleum consumption, but the electricity grid mix used to charge EVs significantly affects the mitigation potential.
- Even in modeled scenarios where BEVs charge from a carbon-intensive grid mix (i.e., electricity generation from mostly coal-fired power plants), total vehicle life-cycle GHG emissions from BEVs are less than conventional gasoline vehicles.
- The environmental impacts associated with electricity generation and consumption during the use of EVs depends on the location and timing of vehicle charging. Among EVs, the use of PHEVs would cause no more SO_x, NO_x, and GHG emissions than hybrids aggregately throughout the U.S. if charged during off-peak electricity generating hours. Furthermore, they will likely cause less emissions than hybrids in areas with non-coal generated electricity regardless of charging time.

As summarized in Table 6.2.2-1, the energy and GHG emissions associated with the EV life cycle are compared to a conventional vehicle across three studies. Note that due to underlying assumptions about the vehicle type, vehicle life, specific EV battery, life-cycle boundaries, and electricity grid mix, the energy and GHG emissions listed in the table are not directly comparable across studies. However, the table clearly indicates that despite different assumptions, all studies find that the total life-cycle energy and GHG emissions on a per-mile basis are significantly less for BEVs compared to conventional vehicles. In addition, on a per-mile-traveled basis across different types of EVs, the GHG emissions and energy impacts are dominated by the use stage (i.e., the impacts associated with electricity generation upstream).

Table 6.2.2-1 indicates the use stage is the dominant contributor to environmental impacts across EV life cycle, representing 67 to 84 percent of the total life-cycle impacts, although the environmental impacts of the use phase are highly dependent on the mix of fossil fuels used to generate the electricity (Notter et al. 2010). This was demonstrated in a recent study in which Notter et al. (2010) adjusted the underlying baseline electricity grid mix (representing the average electricity production mix in Europe) to hard coal (i.e., anthracite coal), and found that the Ecoindicator 99 impact category[19] for the use stage increased by 13 percent, demonstrating substantially greater environmental impacts. Alternatively,when the authors adjusted the baseline to a scenario in which EVs were powered by electricity produced using hydropower, the Ecoindicator99 impact category for the use stage decreased by more than 40 percent, demonstrating substantially decreased environmental impacts. Therefore, the relative share of environmental burdens associated with the use stage of EVs is significantly affected by the underlying electricity grid mix.

[19] Ecoindicator 99 (EI99) is a weighted average environmental impact assessment score consisting of human health and ecosystem quality impact categories.

Table 6.2.2-1. Comparison of Vehicle Life-cycle Energy and GHG Emissions

Environmental Impact Study	**Energy (Btu per mile)**[a]					**GHG Emissions (grams CO_2e per mile)**[a]				
	Notter et al. (2010)[b]		**Samaras et al. (2008)**		**Gaines et al. (2011)**[c]	**Notter et al. (2010)**[d]		**Samaras et al. (2008)**[e]		**Gaines et al. (2011)**
Vehicle Type	BEV	CV	BEV (PHEV 30)[e]	CV	BEV (PHEV 20)[f]	BEV	CV	BEV (PHEV 30)[f]	CV	BEV (PHEV 20)[f]
Vehicle Production	1,140	1,203	610	610	600	67	68	56	56	NE
Battery Production	317	0	76	0	100	19	0	5	0	NE
Use	3,424	4,827	2,898	4,881	3,800	175	336	233	377	NE
Total	4,881	6,030	3,585	5,491	4,500	261	404	295	433	NE

a. NE = not estimated; BEV = battery electric vehicle; CV = conventional vehicle; Btu = British thermal unit; CO_2e = carbon dioxide equivalent; PHEV = plug-in hybrid electric vehicle.
b. Vehicle production stage includes maintenance and end of life. Vehicle use stage includes road infrastructure.
c. Energy estimates derived from graph Figure 5 in Gaines et al. (2011) (p. 13).
d. Assumes average electricity production mix in Europe.
e. Assumes U.S. average electricity production mix.
f. PHEV with a 30-kilometer (18.6-mile) all-electric driving distance capacity.
g. PHEV with a 20-mile all-electric driving distance capacity.

Another study by Samaras et al. (2008) performed a similar sensitivity analysis of use-stage GHG emissions due to differences in underlying electricity generation grid mix for three different PHEV all-electric travel ranges – 30 kilometers (19 miles), 60 kilometers (37 miles), and 90 kilometers (56 miles), denoted in Table 6.2.2-2 as PHEV 30, PHEV 60, and PHEV 90, respectively. In the base-case scenario, the carbon intensity of the electricity used was assumed to be equivalent to the average intensity of the U.S. power sector, or 670 grams (approximately 1.5 pounds) CO_2e per kilowatt-hour. In the carbon-intensive scenario, the authors assumed that coal supplied most of the fuel source used to generate electricity, with the resultant emissions totaling roughly 950 grams (2 pounds) CO_2e per kilowatt-hour. Finally, in the low-carbon scenario, the authors assumed an electricity grid mix dominated by renewable energy and nuclear power, amounting to only 200 grams (approximately 7 ounces) CO_2e per kilowatt-hour required to generate electricity used to power EVs (Table 6.2.2-2). The study concluded that PHEVs charged from an electricity source equivalent to the average of the U.S. power sector (the base-case) reduced the use-stage GHG emissions by 38 to 41 percent compared to conventional gasoline vehicles, and by 7 to 12 percent compared to HEVs. In terms of total life-cycle impacts, in the carbon-intensive scenario, the total life-cycle GHG impacts of PHEVs are 9 to 18 percent higher compared to HEVs, but still less (15 to 21 percent) than conventional gasoline vehicles. Finally, in the low-carbon scenario, total life-cycle GHG impacts of PHEVs are 51 to 63 percent less than conventional vehicles and 30 to 47 percent less than HEVs. The results of the sensitivity analysis by Samaras et al. (2008) illustrate that through different scenarios of upstream electricity generation mix, the GHG implications of the full life cycle of an EV (including upstream battery production, vehicle production, and use) are less than those of a conventional vehicle.

Table 6.2.2-2. Sensitivity of Life-cycle GHG Impacts Associated with BEVs from Samaras et al. (2008)

	Life-cycle GHG Emissions (grams CO_2e per kilometer)[a]				
	CV	**HEV**	**PHEV 30**	**PHEV 60**	**PHEV 90**
Base-case (670 grams CO_2e per kWh)	269	192	183	181	183
Carbon-intensive scenario (950 grams CO_2e per kWh)	276	199	217	228	235
Low-carbon scenario (200 grams CO_2e per kWh)	257	180	126	104	96

a. CO_2e = carbon dioxide equivalent; CV = conventional vehicle; HEV = hybrid electric vehnicle; PHEV = plug-in hybrid electric vehicle; kWh = kilowatt-hour.

A more comprehensive analysis of the environmental impacts associated with upstream electricity production, in which detailed electricity supply and demand models were developed by Elgowainy et al. (2010), simulated regional power grids to determine the influence of different recharging scenarios for EVs. This study concluded that a shift from conventional vehicles to EVs would significantly reduce petroleum consumption, but that the corresponding reduction in GHG emissions would depend on the electricity generation mix used for recharging EVs. For example, replacing internal combustion engine vehicles with PHEVs using electricity equivalent to the U.S. average electricity generation mix would reduce life-cycle GHG emissions by 20 to 25 percent (Elgowainy et al. 2010). Where EVs are assumed to be charging from a predominantly natural gas grid mix (e.g., the Western Electricity Coordinating Council electricity region), life-cycle GHG emissions are even lower compared to conventional vehicles. However, in a scenario in which EVs charge from a coal-intensive grid mix (e.g., the State of Illinois), the associated life-cycle GHG emissions are comparable to a conventional gasoline vehicle. While it is impossible to know exactly where PHEVs will be deployed and linked to the grid, general regional forecasts anticipate that “the adoption of electric cars will likely occur first in the West Coast states” (Becker et al. 2009) with the highest amount of the EVs located in California (CAR 2011, Becker et al. 2009). In addition, study projections indicate that most PHEVs will be heavily concentrated in metropolitan areas (KEMA and IRC 2010). These projections are based on current hybrid registration rates by state, a likely indicator of where future EVs will be deployed.

When analyzing emissions from PHEVs, Hadley and Tsvetkova (2008) note that not only *location*, but also the *time* of charging will affect the level of emissions produced. As discussed above, the location of charging determines the mix of energy used to produce electricity, some sources (such as coal) being more carbon-intensive than others (such as natural gas). Similarly, the time of charging, specifically during peak or non-peak hours, determines if the use of less-efficient gas turbines and gas-fired steam turbines will be necessary to meet additional electricity demand.

To compare emissions from efficient hybrid vehicles (which are not charging from the grid) to PHEVs (which are assumed to be charging during peak energy demand hours) Hadley and Tsvetkova (2008) analyze fuel use, emissions, and cost of using a PHEV versus a hybrid vehicle.[20] Assuming a constant market penetration of 25 percent of all new vehicles sold in each region of the U.S. to be either PHEVs or hybrids by 2020 the study aggregates regional fuel use, emissions, and cost under both *PHEV*-dominated market (with no hybrids) and a

[20] Both vehicles are assumed to travel up to 20 miles per day. The hybrid vehicle fuel economy is assumed to be 40 miles per gallon.

separate *hybrid*-dominated market (with no PHEVs). Conventional gasoline/deisel vehicles are not included in the comparison. Based on this PHEV-hybrid comparison, Hadley and Tsvetkova find that CO_2 emissions on the aggregate basis for the U.S. are slightly higher from the PHEVs scenario than from hybrids (37.8 versus 34.4 million tons in 2020, and 94.5 versus 88.5 million tons in 2030). In addition, national SO_x and NO_x emissions are much higher from the PHEVs scenario than from the hybrids scenario (for SO_x, 246 thousand tons in the PHEV scenario versus virtually no emissions in the hybrids scenario in 2020, and 500 thousand tons in the PHEV scenario versus virtually no emissions in the hybrids scenario in 2030; for NO_x, 44.5 versus 7.8 and 102.2 versus 20.2 thousand tons of NO_x in 2020 and 2030, respectively, for PHEVs versus 7.8 and 20.2 thousand tons for hybrids in the same years). However, it is important to note that these results do not account for the potential for regulated caps on SO_x and NO_x emissions from electricity generation that will mitigate their overall increase.

If PHEV charging were to occur during non-peak hours and use electricity generated from non-coal sources, PHEVs might produce lower CO_2 emissions than hybrids (Hadley and Tsvetkova 2008). For example, in Hadley and Tsvetkova's PHEV-hybrid emissions comparison for the Western Electricity Coordinating Council-California region, PHEV CO_2 emissions are modeled to be *lower* than hybrid carbon emissions (3.3 versus 4.6 million tons in 2020 and 9.3 versus 11.7 million tons in 2030), due to the less carbon-intensive electricity grid mix in that region. Because it is more likely that market penetration will increase in certain regions, like the Western Electricity Coordinating Council-California region, compared to other regions like the southern and central United States (CAR 2011, Becker et al. 2009), CO_2 emissions from PHEVs could be lower than hybrid CO_2 emissions due to the higher use of non-coal generated electricity in these areas (Hadley and Tsvetkova 2008).

In terms of air quality emissions, other studies have reported on the life-cycle criteria pollutant emissions from various vehicle and fuel systems compared to EVs using both the U.S. and California electricity generation mix. In general, the California electricity generation mix is less carbon-intensive compared to the national average electricity generation mix.[21] The results of a study by Huo et al. (2009) show that EVs powered using the California electricity generation mix have roughly 30 percent lower life-cycle NO_x emissions, 50 percent lower emissions of particulate matter with diameters of 10 micrograms or less (PM_{10}), and 50 percent lower emissions of particulate matter with diameters of 2.5 micrograms or less ($PM_{2.5}$) compared to vehicles powered by the U.S. national average electricity generation mix.[22] The large differences in NO_x, PM_{10}, and $PM_{2.5}$ emissions are due to the higher contribution of coal in the average U.S. electricity generation mix. However, emissions of volatile organic compounds (VOCs) and carbon monoxide throughout the life cycle of EVs are similar for both electricity generation mix assumptions.

A recent study ("Vehicle Electrictrification Study") by the International Council on Clean Transportation (ICCT) presents air pollution results for the incremental criteria air pollutants

[21] Huo et al. (2009) assume a U.S. electricity generation mix of 48.7 percent coal, 22.5 percent natural gas, 17.6 percent nuclear, 2.6 percent residual oil, 1.3 percent biomass, and 7.3 percent others. The report assumes a California electricity generation mix of 21.0 percent coal, 42.0 percent natural gas, 15.6 percent nuclear, 0.6 percent residual oil, 1.5 percent biomass, and 19.3 percent others (p. 1797). In general, the California electricity generation mix is less carbon intensive compared to the national average electricity generation mix. Huo et al. (2009) assume a U.S. electricity generation mix of 48.7 percent coal, 22.5 percent natural gas, 17.6 percent nuclear, 2.6 percent residual oil, 1.3 percent biomass, and 7.3 percent others. The report assumes a California electricity generation mix of 21.0 percent coal, 42.0 percent natural gas, 15.6 percent nuclear, 0.6 percent residual oil, 1.5 percent biomass, and 19.3 percent others (p. 1797).

[22] In Huo (2009), the well-to-wheels boundaries include feedstock recovery and processing, feedstock transportation and storage, fuel production, fuel transportation, storage and distribution, and vehicle operation activies.

resulting from the electricity needed to power BEVs based on California's grid mix target of 33 percent renewable electricity in 2020. The incremental criteria air pollutants for NO_x and SO_x associated with electricity production are "significantly less than" air pollutant emissions associated with upstream refinery operations used to produce petroleum-derived fuels (Shulock 2011). However, VOCs and fine particulate matter are comparable. ICCT concludes that by accounting for both tailpipe and upstream emissions, EVs "should have a very positive overall effect on ozone and fine particulates." Relevant to vehicles in California, the ICCT study also references another life-cycle study developed by TIAX (TIAX LLC 2007[23]) to show that the total cradle-to-gate NO_x emissions associated with model year 2010 conventional gasoline vehicles (0.29 grams NO_x per mile) are significantly higher than a BHEV (0.01 grams NO_x per mile), assuming an electricity generation grid mix that is natural gas combined with California-mandated renewable electricity generation sources.

6.3 Conclusions

The overarching conclusion based on this synthesis of the literature considered is that with the exception of a few cases (e.g., magnesium material manufactured via coal-intensive process substitutes for steel with very high recycled content or titanium material substitution of mild steel in automotive parts), all of the materials and technologies analyzed in this literature synthesis appear to reduce GHG emissions, energy use, and most other environmental impacts when considered on a life-cycle basis.

The LCA literature synthesis revealed the following trends for emerging materials and technologies:

- Aluminum and high-strength steel material substitution are both effective at reducing life-cycle energy use and GHG emissions (i.e., the increased energy use and GHG emissions at the vehicle production stage are offset by use-phase savings over the vehicle life).
- Materials that use a greater share of recycled (i.e., secondary) materials achieve greater energy use and GHG savings. The measures of energy use and GHG savings achieved by substituting alternative materials are sensitive to assumptions regarding the recycled content of (1) the specific alternative material used and (2) the steel that is being replaced.
- Polymer composites (including those reinforced with glass, carbon fiber, or nanoclays) used in vehicle body panels are more energy and GHG intensive to produce in relation to mild steel; however, over the full life cycle, these lightweight, high-strength materials provide lower environmental impacts (e.g., GHG emissions) compared to mild steel. There is a need for additional study of the impacts of composite recycling, reparability, and use of recycled content.
- The substitution of magnesium for conventional steel in vehicles requires more energy use in the vehicle production stage. However, across the full vehicle life cycle, magnesium-substituted vehicles have much higher fuel efficiencies than conventional vehicles due to lighter vehicle weights resulting from the low density of magnesium. This, in turn, lowers the energy use below that of conventional vehicles. However, the environmental impacts in terms of GHG emissions are determined by the manufacturing processes to generate magnesium, the vehicle components substituted with magnesium, and the availability of recycling of magnesium parts at the end-of-life.

[23] pp. 3–5.

- Life-cycle GHG emissions (and most other environmental impacts) on a per-mile-traveled basis across different types of EVs (e.g., hybrids, BEVs, and PHEVs) are dominated by the use stage (i.e., the impacts associated with electricity generation upstream).
- The environmental impacts associated with Li-ion battery production are small (less than 10 percent of the total life-cycle GHG emissions of EVs).
- There is a potential for EVs to significantly reduce petroleum energy use, GHG emissions, and other environmental impacts associated with reduced petroleum consumption, but the electricity grid mix used to charge EVs will significantly affect the mitigation potential.
- Even in modeled scenarios in which EVs charge from a carbon-intensive grid mix (i.e., electricity generation from mostly coal power plants), the vehicle life-cycle GHG emissions from EVs are less than conventional gasoline vehicles.
- Among EVs, PHEVs would cause no more SO_x, NO_x, and GHG emissions than hybrids aggregately throughout the United States if charged during off-peak electricity generating hours, and would likely cause less emissions than hybrids in areas with non-coal generated electricity regardless of charging time.

CHAPTER 7 OTHER IMPACTS

This chapter describes the affected environment and environmental consequences of the Proposed Action and alternatives on land use and development (Section 7.1), hazardous materials and regulated wastes (Section 7.2), historic and cultural resources (Section 7.3), noise (Section 7.4), safety impacts to human health (Section 7.5), and environmental justice (Section 7.6). It also addresses unavoidable adverse impacts (Section 7.7), short-term uses and long-term productivity (Section 7.8), and irreversible and irretrievable commitments of resources (Section 7.9).

7.1 Land Use and Development

7.1.1 Affected Environment

Land use and development refers to human activities that alter land (e.g., industrial and residential construction in urban and rural settings, or clearing of natural habitat for agricultural or industrial use). For purposes of this EIS, shifts in mining practices, agricultural practices, and development land use patterns are analyzed.

7.1.2 Environmental Consequences

Shifts toward more efficient, lighter vehicles, either as a result of consumer preference for fuel-efficient vehicles or mass reduction design decisions by manufacturers, could result in changes in mining land-use patterns. Mining for the minerals needed to construct these lighter vehicles (primarily aluminum and magnesium) could shift some metal-extraction activities to areas rich in these resources. Schexnayder et al. (2001) noted that such a shift in materials "could reduce mining for iron ore in the United States, but increase the mining of bauxite for aluminum, magnesium, titanium, and other materials in such major countries as Canada, China, and Russia, and in many small, developing countries, such as Guinea, Jamaica, and Sierra Leone."

Depending on how manufacturers achieve reductions in vehicle weight, there could be shifts in mining from areas containing iron to those containing aluminum and magnesium, and shifts from facilities that process iron ore for iron and steel to those that process bauxite for aluminum and brine for magnesium (Schexnayder et al. 2001). Relocating mining to new sites could result in environmental impacts, such as destruction of natural habitat due to altered land cover. However, because of the uncertainty surrounding how manufacturers would meet the new requirements and the fact that the Proposed Action would not specifically require vehicle mass reduction (much less specific engineering and materials shifts to reduce vehicle mass), these potential environmental impacts are not quantifiable.

The production of biofuels for use in some vehicles covered by the proposed rule could adversely impact land use. Ethanol is the most commonly used biofuel for vehicles and its main source in the United States is corn. Due to increasing gasoline prices and new bioenergy policies, ethanol production in the United States increased by 9 billion gallons and increased corn acreage by 10 percent from 2000 to 2009 (ERS 2011). If the demand for ethanol continues to increase, more corn would need to be harvested to meet ethanol, livestock, and food demands. In 2006, an estimated 71 million acres of corn were harvested. Nearly 137 million acres would be needed to produce enough corn and resulting ethanol (56.4 billion gallons) to substitute for approximately 20 percent of petroleum imports (Yacobucci and Schnepf 2007).

Growing biofuel feedstocks removes CO_2 from the atmosphere; therefore biofuels can, in theory, reduce GHG emissions relative to fossil fuels. In practice, however, land use changes resulting from increased ethanol production could increase GHG emissions and cause other environmental impacts. Although most increased corn production for ethanol is from farms previously specializing in soybeans, other land is indirectly affected (ERS 2011). Some farms shift from other crops to produce soybeans in response to the farms that shifted from soybeans to corn. The Economic Research Service (ERS 2011) found that this shift resulted in a reduction in cotton acreage, conversion of land for uncultivated hay to cropland, and the expansion of double cropping. The conversion of previously uncultivated land to cropland, which represents about a third of the average increase in harvested acreage, is an indirect land use change that could accelerate nutrient runoff and soil erosion (ERS 2011). However, ethanol production might not require an equivalent amount of additional crops to be grown for livestock feed, because the ethanol by-product, dry distillers' grains, replaces roughly one-third of the animal feed otherwise diverted (Searchinger et al. 2008).

The conversion from forests or grassland to plowed agricultural land could also sacrifice carbon storage and sequestration at the time of conversion when much of the carbon previously stored in plants and soils is released into the atmosphere through decomposition or fire. Also, the new planted crops might not be able to store an equivalent amount of carbon (Searchinger et al. 2008).

However, it is important to note that the consequences to land use in this section do not necessarily result directly from the proposed standards. The current production of ethanol is affected primarily by the Renewable Fuel Standard (RFS), which establishes targets for several categories of renewable fuels consumption, including corn based ethanol. The RFS caps the corn ethanol target at 15 billion gallons per year beginning in 2015. It is not expected that the proposed rule will impact the production of corn based ethanol.

By reducing fuel costs per mile, increased fuel economy could provide an incentive for increased driving and lead to higher VMT. In areas where the highway network, infrastructure availability, and housing market conditions allow, this could increase demand for low-density residential development beyond existing developed areas. Undeveloped land could be converted to support low-density suburban sprawl. Residential communities in such areas are highly dependent on automobiles for travel and are associated with relatively high VMT per household (FHWA 1998). Many agencies are implementing measures, such as funding smart-growth policies, to change human behavior and settlement patterns to reduce VMT and fuel use to meet climate change goals (Moore et al. 2010). *See* Chapter 2 for more information regarding VMT and Chapter 8 for a discussion of mitigation.

7.2 Hazardous Materials and Regulated Wastes

7.2.1 Affected Environment

For purposes of this analysis, hazardous wastes are defined as any item or agent (biological, chemical, or physical) which has the potential to cause harm to humans, animals, or the environment, either by itself or through interaction with other factors. Hazardous wastes are generally designated as such by individual states or EPA under the Resource Conservation and Recovery Act of 1976. Additional federal and state legislation and regulations, such as the Federal Insecticide, Fungicide, and Rodenticide Act, determine handling and notification standards for other potentially toxic substances. The relevant sources of impacts of the proposed rule are hazardous materials and wastes generated during the oil-extraction and refining processes, agricultural production and mining activities, and vehicle batteries.

Hazardous wastes produced from oil and gas extraction and refining can present a threat to human and environmental health. Onshore environmental effects result mostly from the improper disposal of saline water produced with oil and gas, from accidental releases of hydrocarbon and produced water, and from oil wells that were improperly sealed when abandoned (Kharaka and Otton 2003). Offshore effects result from improperly treated produced water released into the waters surrounding the oil platform (EPA 1999). Operation of motor vehicles during the extraction process results in air emissions that affect air quality through combustion of petroleum-based fuels releasing VOCs, SO_2, NO_x, CO, and other air pollutants (EPA 1995a, EPA 2011h). In the atmosphere, SO_2 and NO_x contribute to the formation of acid rain (the wet, dry, or fog deposition of SO_2 and NO_x), which enters waterbodies either directly or as runoff from terrestrial systems (*see* Chapter 4 for more information on air quality) with negative effects on water resources, plants, animals, and cultural resources. Oil extraction activities could also impact biological resources through habitat destruction and encroachment, raising concerns about their effects on the preservation of animal and plant populations and their habitats.

Wastes produced from the life cycle of vehicle batteries differ depending on material composition. During the life cycle of batteries, there is a potential for resource extraction, production, manufacturing, and disposal to generate wastes, which would contribute to air pollution and landfill waste.

7.2.2 Environmental Consequences

The projected reduction in fuel production and combustion as a result of the Proposed Action could lead to a reduction in the extraction and refining of petroleum for the transportation sector. Wastes produced during the petroleum-refining process are primarily released to the air and water, accounting for 75 percent (air emissions) and 24 percent (wastewater discharges) of the total amount of waste produced during this process (EPA 1995a). EPA defines a release as the "on-site discharge of a toxic chemical to the environment…emissions to the air, discharges to bodies of water, releases at the facility to land, as well as contained disposal into underground injection wells" (EPA 1995a). EPA reports that 9 of the 10 most common toxic substances released by the petroleum-refining industry are volatile chemicals, highly reactive substances prone to state changes or combustion, that include benzene, toluene, ethylbenzene, xylene, cyclohexane, 1,2,4-trimethylbenzene, and ethylbenze (EPA 1995a). These substances are present in crude oil and in finished petroleum products.

Potential spills of oil or other hazardous materials during oil and gas extraction and refining can lead to contamination of surface water and groundwater, and can result in impacts to drinking water and marine and freshwater ecosystems. EPA estimates that, of the volume of oil spilled in "harmful quantities" (as defined under the Clean Water Act), 83.8 percent was deposited in internal/headland waters and within 3 miles of shore, with 17.5 percent spilled from pipelines, often in inland areas (EPA 2004b).

Several of the produced VOCs emitted through oil and gas extraction and refining contribute to ground-level ozone and smog and are also known or suspected carcinogens, and many others are known to cause respiratory problems and impair internal-organ functions, particularly in the liver and kidneys (EPA 1995a). Potentially dangerous substances commonly released during the refining process include ammonia, gasoline additives (methanol, ethanol, and methyl tertiary butyl ether), and chemical feedstocks (propylene, ethylene, and napthalene) (EPA 1995a). Spent sulfuric acid is by far the most commonly produced toxic substance; however, it is generally reclaimed instead of released or transferred for disposal (EPA 1995a). Ammonia is a form of nitrogen and can contribute to eutrophication in surface waters. Once present in surface waters, air pollutants can cause acidification of waterbodies, changing the pH of the system and affecting the function of freshwater ecosystems. EPA (2008b) states that plants and animals in a given ecosystem are highly interdependent due to the many connections between them; therefore, changes in pH or aluminum levels can severely affect biodiversity. As lakes and streams become more acidic, the numbers and types of fish and other aquatic plants and animals in these waters could decrease.

Oil exploration and extraction result in intrusions into onshore and offshore natural habitats and can even involve construction within natural habitats. There are serious environmental concerns for ecosystems that experience encroachment and chronic effects of drilling for benthic (bottom-dwelling) populations, migratory bird populations, and marine mammals (Borasin et al. 2002).

Acid rain caused from the release of VOCs has been shown to negatively affect forest ecosystems, both directly and indirectly. These impacts include stunted tree growth and increased mortality, primarily as a result of the leaching of soil nutrients (EPA 2007c). Declines in biodiversity of aquatic species and changes in terrestrial habitats likely have ripple effects on other wildlife that depend on these resources. Eutrophication of aquatic systems, which can ultimately result in the death of fish and other aquatic animals, is enhanced by acid rain (Lindberg 2007). Damage from acid rain also substantially reduces the societal value of buildings, bridges, and cultural objects made from materials such as bronze, marble, or limestone (*see* Section 7.3). The projected reduction in fuel production and combustion as a result of the Proposed Action could lead to a reduction in the amount of pollutant emissions that cause acid rain.

Motor vehicles and the motor vehicle equipment industry, and businesses engaged in the manufacture and assembly of cars and trucks produce hazardous materials and toxic substances. EPA reports that solvents (e.g., xylene, methyl ethyl ketone, and acetone) are the most commonly released toxic substances it tracks for this industry (EPA 1995a). These solvents are used to clean metal and in the vehicle-finishing process during assembly and painting (EPA 1995a). Xylene and methyl ethyl ketone act as air pollutants, causing severe danger through inhalation, and are VOCs (EPA 1995a). In addition, xylene has the potential to contaminate soils and groundwater if improperly handled. Other industry wastes include metal paint and component-part scrap.

To comply with the proposed standards, some manufacturers might choose to substitute lighter weight materials (e.g., aluminum, high strength steel, magnesium, titanium, or plastic) for conventional vehicle materials (e.g., conventional steel and iron). Studies have suggested that the substitution of lighter weight materials to increase fuel economy could increase the total waste stream resulting from automobile manufacturing (Schexnayder et al. 2001). Mining wastes generated during the extraction of lighter raw materials would likely increase substantially, primarily due to aluminum mining, and other production wastes (e.g., from refining of aluminum and plastic manufacturing) could also increase because of a greater demand for lightweight vehicles (Schexnayder et al. 2001, Dhingra et al. 1999). The extraction and processing of these metals and the production of man-made fibers and plastics also generate various hazardous wastes (EPA 1995b, EPA 1997). An assessment of the solid and hazardous wastes generated during the production of three light-weight concept cars concluded the net generation of waste would decrease versus conventional vehicles (Overly et al. 2002). A separate study noted that the generation of most hazardous materials of particular concern to human health (e.g., cadmium, chlorine, and lead) emitted during the production of vehicles appeared to decrease in the new generation vehicle models compared to conventional models (Schexnayder et al. 2001). Recycling vehicles at the end of vehicle life could help offset some of the projected net increase in waste production versus vehicles constructed primarily of steel and iron.

There are differences in waste generated from different types of electric batteries. Both solid and hazardous wastes are produced through the life cycle of the batteries, including production and after their useful life in automobiles. Conventional batteries are based on a lead-acid composition, whereas the two most common types of batteries for hybrid and plug-in electric vehicles (PHEVs) are made from nickel-metal hydride (NiMH) and lithium-ion (Li-ion) chemistries. NiMH battery energy density is still insufficient for full electric vehicles (Boncourt 2011). However, lithium technology offers an effective ratio of energy storage and power for a lower weight. Li-ion batteries can be adapted for the needs of either PHEVs or full battery electric vehicles (BEVs) (Boncourt 2011). Processing the minerals to create the materials used in batteries releases hazardous wastes. The EPA classifies nickel as a hazardous air pollutant, but does not list lithium (EPA 2010e).

Recycling of lead-acid batteries has long been practiced, and NiMH and Li-ion batteries can also be recycled. At the end of the useful life of an electric vehicle (EV) or PHEV, the battery will likely not be fully exhausted and could be used for other purposes (EPA, NHTSA, and CARB 2010). When these new technology batteries can no longer be reused, most of the materials can then be reprocessed and recycled. The electrode grids from spent lead-acid batteries are often corroded and stretched out, which results in reduced or lost electrical contact and prevents the battery components from being reused; instead, they must be reprocessed (Gaines and Singh 1995). NiMH and Li-ion batteries can also be reprocessed to recycle their materials. If NiMH is recycled using the pyrometallurgical process, only the nickel-rich materials can be recovered, whereas reuse of 86 percent of nickel alloys is possible with the sole use of the physical separation process (Espinosa et al. 2004). Nickel is a valuable metal, which creates an incentive to recycle. Some facilities are now recycling Li-ion batteries (Hamilton 2009).

Disposing of batteries could lead to adverse impacts due to the risk of toxic chemicals being released into the environment. Schexnayder et al. (2001) concluded that NiMH and Li-ion batteries do generate more waste than lead-acid batteries, and Li-ion batteries contribute a slightly higher amount compared to NiMH. However, the increased waste from lithium batteries is mostly solid, and these batteries are only slightly toxic. Li-ion batteries are less toxic than lead-acid batteries and NiMH batteries; lithium as a constituent in Li-ion batteries represents a small fraction (typically from 1 to 3 percent, depending on specific chemistry) of total battery composition (Gaines et al. 2011).

7.3 Historic and Cultural Resources

7.3.1 Affected Environment

The National Historic Preservation Act of 1966 (16 U.S.C. 470 et seq.), Section 106, states that agencies of the Federal Government must take into account the impacts of their actions to historic properties; the regulations to meet this requirement are provided at 36 CFR Part 800. This process, known as the “Section 106 process,” is intended to support historic preservation and mitigate impacts to significant historical or archaeological properties through the coordination of federal agencies, states, and other affected parties. Historic properties are generally identified through the *National Register of Historic Places*, which lists properties of significance to the United States or a particular locale because of their setting or location, contribution to or association with history, or unique craftsmanship or materials.[1]

7.3.2 Environmental Consequences

For this analysis, acid rain, which can be created from processing petroleum products and the combustion of petroleum-based fuels, is the identified relevant impact.

Acid rain, the primary source of which is the combustion of fossil fuels, is one cause of degradation to exposed cultural resources and historic sites (EPA 2007d). EPA states that the corrosion of metals and the deterioration of paint and stone can be caused by both acid rain and the dry deposition of pollution, which can reduce the cultural value of buildings, statues, cars, and other historically significant materials (EPA 2007d). The projected reduction in fuel production and combustion as a result of the Proposed Action and alternatives could lead to a reduction in the amount of pollutant emissions that cause acid rain. A decrease in the emissions of such pollutants could result in a corresponding decrease in the amount of damage to historic and other structures caused by acid rain. However, such effects are not quantifiable due to the inability to distinguish between acid rain deterioration and natural weathering (rain, wind, temperature, and humidity) effects on historic buildings and structures, and due to the varying impact for a specific geographic location of any particular historical resource (Striegel et al. 2003).

7.4 Noise

7.4.1 Affected Environment

To comply with the proposed standards, manufacturers could reduce vehicle mass or increase the production of hybrid vehicles, which could lead to some reduction in the amount of noise produced by motor vehicles. Noise, vibration, and harshness (NVH) generated by motor vehicles are produced by three main components: the powertrain (consisting of the engine, transmission, exhaust, axle, radiator, and fuel tank) NVH; road and tire NVH; and wind-related NVH (Qatu et al. 2009).

Excessive amounts of noise, which is measured in decibels, can present a disturbance and a hazard to human health at certain levels. Potential health hazards from noise range from annoyance (sleep disturbance, lack of concentration, and stress) to hearing loss at high levels (Passchier-Vermeer and Passchier 2000). The noise from motor vehicles has been shown to be one of the primary causes of noise disturbance in homes (Theebe 2004, Ouis 2001). Noise generated by vehicles causes inconvenience, irritation, and potentially even discomfort to occupants of other vehicles, to pedestrians and other bystanders, and to residents or occupants

[1] National Register-eligible properties must also be sites that meet one or more of the following criteria (36 CFR 60.4): are associated with events that have made a significant contribution to the broad patterns of our history; are associated with the lives of persons significant in our past; embody the distinctive characteristics of a type, period, or method of construction, or represent the work of a master, or possess high artistic values, or represent a significant and distinguishable entity whose components may lack individual distinction; have yielded, or may be likely to yield, information important in prehistory or history.

of surrounding property. Exposure to chronic noise disturbances from motor vehicles can impair senses and disrupt communication signals in wildlife (Barber et al. 2000).

Various advocacy groups, including the National Federation of the Blind, have expressed concerns regarding hybrid electric vehicles (HEVs) not emitting the sounds that pedestrians and bicyclists rely on as a warning of an approaching vehicle. According to a 2009 NHTSA report, *Incidence of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles*, an HEV is twice as likely to be in a crash with a pedestrian or bicycle as an internal combustion engine vehicle (Hanna 2009). The 2011 update to the 2009 NHTSA report had similar crash incidence results. The highest incidence rate for HEV pedestrian crashes is found to occur during low-speed maneuvers such as turning, backing up, or stopping on a roadway, and for bicycle crashes during low-speed maneuvers at an intersection (Wu et al. 2011). For both pedestrian and bicycle crashes, the HEV is found to have a greater crash rate than internal combustion engine vehicles (Wu et al. 2011).

7.4.2 Environmental Consequences

As a result of the rebound effect (the increase in VMT as the cost per mile for fuel decreases), NHTSA predicts that there will be increased vehicle use under all of the action alternatives; higher overall VMT could result in increases in vehicle road noise. However, location-specific analysis of noise impacts is not possible based on available data. Noise levels are location-specific, meaning that factors such as the time of day at which increases in traffic occur, existing ambient noise levels, the presence or absence of noise-abatement structures, and the locations of schools, residences, and other sensitive noise receptors all influence whether there will be noise impacts.

However, at the same time, all of the alternatives could lead to an increase in use of hybrid vehicles and EVs, depending on the mix of technologies manufacturers use to meet the proposed standards, economic demands from consumers and manufacturers, and technological developments. An increased percentage of hybrid vehicles could result in reduced vehicle noise at low speeds, potentially offsetting some of the increase in traffic noise that could otherwise result from increased VMT. However, due to the uncertainty surrounding how manufacturers would meet the new requirements and the location-specific nature of noise impacts, these potential impacts are not quantifiable.

NHTSA plans to address the issue of potential safety impacts related to vehicle noise reduction in a future rulemaking. The Pedestrian Safety Enhancement Act of 2010 requires NHTSA to conduct a rulemaking to establish a Federal Motor Vehicle Safety Standard requiring an alert sound for pedestrians to be emitted by all types of motor vehicles that are electric vehicles or hybrid vehicles.[2] On July 12, 2011, NHTSA published a Notice of Intent to Prepare an Environmental Assessment to analyze the potential environmental impacts of the forthcoming proposal. NHTSA anticipates proposing standards by July 5, 2012,[3] and publishing a final rule by January 4, 2014. The agency will address the safety and potential environmental impacts of that rulemaking as part of that rulemaking process.

[2] The Pedestrian Safety Enhancement Act of 2010 is Public Law 111-373, 124 Stat. 4086 (Jan. 4, 2011). 49 U.S.C. 30111 note.
[3] NHTSA, Notice of Intent to Prepare an Environmental Assessment for Pedestrian Safety Enhancement Act of 2010 Rulemaking. 76 FR 40860 (July 12, 2011).

7.5 Safety Impacts to Human Health

In developing the proposed rule, NHTSA analyzed how future improvements in fuel economy might affect human health and welfare through vehicle safety performance and the rate of traffic fatalities. To estimate the possible safety effects of the proposed standards, NHTSA performed research using statistical analysis of historical crash data and used an engineering approach to investigate the cost and feasibility of mass reduction of vehicles while maintaining safety and other desirable qualities. The mass reduction amounts in NHTSA's analysis were chosen based both on the agency's assumptions about how much is technologically feasible, and to find a way by which manufacturers could comply with the standards in a safety-neutral manner. Using these mass reduction amounts, NHTSA's analysis for the proposed standards projects an approximately neutral effect on fatalities through 2025, although the results are sensitive to decisions made by manufacturers on how they choose to reduce mass. For details about this analysis, *see* the Notice of Proposed Rulemaking.

7.6 Environmental Justice

Executive Order (EO) 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations,*[4] directs federal agencies to "promote nondiscrimination in federal programs substantially affecting human health and the environment, and provide minority and low-income communities access to public information on, and an opportunity for public participation in, matters relating to human health or the environment." EO 12898 also directs agencies to identify and consider disproportionately high and adverse human health or environmental effects of their actions on minority and low-income communities, and provide opportunities for community input in the NEPA process, including input on potential effects and mitigation measures. CEQ has provided agencies with general guidance on how to meet the requirements of the EO as it relates to NEPA (CEQ 1997c).

DOT Order 5610.2, *Department of Transportation Actions To Address Environmental Justice in Minority Populations and Low-Income Populations,*[5] describes the process for DOT agencies to incorporate environmental justice principles in programs, policies, and activities. It also defines the terms "minority" and "low-income" in the context of DOT's environmental justice analyses. Minority is defined as a person who is Black, Hispanic, Asian American, or American Indian or Alaskan Native. Low-income is defined as a person whose household income is at or below the Department of Health and Human Services poverty guidelines. The term "environmental justice populations" refers to groups composed of minorities and low-income persons who live in proximity or are similarly impacted by DOT programs, policies, or activities.

On August 4, 2011, the Secretary of Transportation, along with heads of other federal agencies, signed a Memorandum of Understanding on Environmental Justice and Executive Order 12898 confirming the continued importance of identifying and addressing environmental justice considerations in agency programs, policies, and activities as required by EO 12898. As part of the Memorandum of Understanding, each federal agency agreed to review and update their existing environmental justice strategy as appropriate, and to publicize the updated strategy. Accordingly, DOT has reviewed and updated its environmental justice strategy as appropriate.

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[4] *See* Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, 59 FR 7629 (Feb. 16, 1994).

[5] *See* Department of Transportation Actions To Address Environmental Justice in Minority Populations and Low-Income Populations. 62 FR 18377 (Apr. 15, 1997).

The updated strategy continues to reflect DOT's commitment to environmental justice principles and to integrating those principles into DOT programs, policies, and activities.[6]

7.6.1 Affected Environment

The affected environment for this Proposed Action is nationwide, with a focus on areas and groups most exposed to environmental and health effects of oil production, distribution, and consumption and to the impacts of climate change. Examples are areas where oil production and refining occur, areas in the vicinity of roadways, and urban areas subject to the heat island effect.[7]

There is evidence that proximity to oil refineries might be correlated with the incidence of cancer and leukemia (Pukkala 1998, Chan et al. 2006). There is also evidence that proximity to high-traffic roadways could result in adverse cardiovascular and respiratory effects, among other possible impacts (HEI 2010, Heinrich and Wichmann, 2004, Salam et al. 2008, Samet 2007, Adar and Kaufman 2007). Climate change can affect overall global temperatures, which could affect the number and severity of outbreaks of vector-borne illnesses (CCSP 2008f). Chapters 3, 4, and 5 of this EIS discuss the connections between oil production, distribution, and consumption and their health and environmental impacts. The following paragraphs describe the extent to which minority and low-income populations might be more exposed or vulnerable to such effects.

Existing studies have found mixed evidence on whether there is a correlation between proximity to oil refineries and residence of low-income and minority populations (Fischbeck et al. 2006) or have cited anecdotal evidence (O'Rourke and Connolly 2003). There is some evidence of proximity of low-income populations to other types of industrial facilities (Graham et al. 1999, Jerrett et al. 2001). It is unclear whether any correlation between the location of industrial facilities and the presence of minority and low-income populations is due to the facility siting process or to real-estate market dynamics and migration after facilities are sited (Pastor et al. 2001, Graham et al. 1999, Morello-Frosch 2002). Lynch et al. (2004) examined whether race or economic characteristics of an area affect the monetary penalties assessed against petroleum refineries for violations of federal environmental laws. They found mixed evidence, with results depending on how the area affected by the refinery is defined. Performing a multivariate statistical analysis, Graham et al. (1999) found little support for the hypothesis that minority or low-income populations are more likely to live near oil refineries.

Whether populations living near mobile sources of pollutants more often have low incomes or are minorities is also often unclear. Although there is some evidence that higher traffic levels depress property values and attract lower income populations, urban development can cause increased traffic in secondary roads and impact relatively expensive housing (O'Neill et al. 2003). Inner-city populations, often low-income and minority, might be more exposed to diesel exhaust emissions from buses and trucks (O'Rourke and Connolly 2003).

Environmental justice populations tend to be concentrated in areas with a higher risk of climate-related impacts, and this geographic placement might put these communities at higher risk from climate variability and climate-related extreme weather events (CCSP 2008f). For example, urban areas often have relatively large environmental justice populations, and are subject to the

[6] DOT will accept public comments on the draft revised strategy until November 30, 2011. *See* <http://www.fhwa.dot.gov/environment/environmental_justice/ej_at_dot/revised_strategy/>. (Accessed: November 12, 2011).

[7] The heat island effect refers to developed areas having higher temperatures than surrounding rural areas.

most substantial temperature increase from climate changes due to the urban heat island effect (CCSP 2008f, Knowlton et al. 2007). Environmental justice populations in coastal urban areas (vulnerable to increases in flooding as a result of projected sea-level rise, larger storm surges, and human settlement in floodplains) are less likely to have the means to quickly evacuate in the event of a natural disaster, and therefore at greater risk of injury and loss of lives (CCSP2008f, GCRP 2009). Independent of proximity to sources of pollution or to locations affected by climate change, low-income and minority populations might be more vulnerable to the health impacts of pollutants and climate change. The 2003 National Healthcare Disparities Report stated that minority and low-income populations tend to have less access to health care services, and services received are more likely to suffer in quality (HHS 2003). Increases in heat-related morbidity and mortality as a result of higher overall and extreme temperatures are likely to disproportionately affect minority and low-income populations, partially as a result of limited access to air conditioning and a result of high energy costs (CCSP 2008f, EPA 2009e, O'Neill et al. 2005).

7.6.2 Environmental Consequences

The reduction in fuel production and consumption by passenger cars and light trucks projected as a result of the proposed standards could lead to a minor reduction in the amount of direct land disturbance as a result of oil exploration and extraction, and the amount of air pollution produced by the oil refineries. To the extent that environmental justice populations live in greater proximity to oil extraction, distribution, and refining, they would be more likely to benefit, but as noted above there is mixed evidence on whether this is the case.

Under the action alternatives, emissions of criteria and hazardous air pollutants are generally anticipated to decline. However, as discussed in Chapter 4, the overall decrease in emissions predicted to occur as a result of the Proposed Action and alternatives is not evenly distributed due to the increase in VMT from the rebound effect and regional changes in upstream emissions. As a result, emissions of some criteria and hazardous air pollutants are predicted to increase in some air quality nonattainment areas in some years. Although the evidence on the residential proximity of environmental justice populations to mobile sources of pollutants is unclear, minority and low-income populations tend to be more vulnerable to the consequences of adverse impacts from air pollutants, as discussed in Section 7.6.1. Also, to the extent that low-income populations live and circulate in neighborhoods where there is a greater presence of older cars, they would be more slowly affected both by the overall decrease in emissions predicted to occur and by the localized increased due to increased VMT from the rebound effect.

All action alternatives are expected to result in fewer adverse impacts as a result of climate change compared to the No Action Alternative. Consequently, minority and low-income populations could be expected to benefit from reduced climate change impacts under the action alternatives.

7.7 Unavoidable Adverse Impacts

As demonstrated in Chapters 3, 4, and 5, stricter fuel economy standards under each of the action alternatives are projected to result in a net decrease in energy consumption and in most vehicle emissions compared to the No Action Alternative. Despite these reductions, total energy consumption and total vehicle emissions under all alternatives are anticipated to increase overall as a result of projected increases in the number of vehicles in use and the total number of miles they are driven each year (as measured by VMT). Increased VMT predicted under all of the action alternatives due to the rebound effect would result in unavoidable adverse impacts, specifically impacts to climate and air quality.

Certain impacts, such as increased global mean surface temperature, sea-level rise, and increased precipitation, are likely to occur as a consequence of accumulated total CO_2 and other GHG emissions in Earth's atmosphere. Neither the Proposed Action nor the other action alternatives alone would prevent these emissions and their associated climate change impacts. As described in Section 5.4, each of the action alternatives would reduce GHG emissions compared to projected levels under the No Action Alternative, therefore diminishing anticipated climate change impacts. Nonetheless, climate impacts would be expected under all action alternatives.

Regarding air quality, certain criteria and toxic air pollutants, such as particulate matter ($PM_{2.5}$), VOCs, and benzene, would exhibit decreases in emissions under all action alternatives and analysis years compared to their levels under the No Action Alternative. Consequently, any adverse impacts to human health associated with these emissions would be expected to be reduced, and no unavoidable adverse impacts from these emissions would be anticipated.

However, emissions of other criteria and toxic air pollutants, such as CO, NO_x, SO_2, acetaldehyde, acrolein, 1,3 butadiene, diesel particulate matter, and formaldehyde could increase under certain action alternatives and analysis years compared to levels projected under the No Action Alternative. Emissions of four of the toxic air pollutants, acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde, are anticipated to increase under all of the action alternatives in at least one of the analysis years, compared to the No Action Alternative. As described above, this is largely a result of higher VMT under the action alternatives. Therefore, the potential for unavoidable adverse impacts on air quality from these emissions depends on the final standards that are selected. As a result of these potential increases in pollutant emissions, some areas, including some nonattainment areas, throughout the United States could experience increases in emissions of criteria and toxic air pollutants. Despite these variations in pollutant emissions across alternatives and by region, overall U.S. health impacts associated with air quality (mortality, asthma, bronchitis, emergency room visits, and work-loss days) are anticipated to decrease with increasing fuel economy across all alternatives as compared to the No Action Alternative. Correspondingly, monetized health benefits are anticipated to also increase under the action alternatives.

7.8 Short-Term Uses and Long-Term Productivity

All of the action alternatives would result in a decrease in crude oil consumption and reduced CO_2 emissions (and associated climate change impacts) compared to the No Action Alternative. To meet the proposed standards, manufacturers would need to apply various fuel-saving technologies during the production of passenger cars and light trucks. NHTSA cannot predict with certainty which specific technologies and techniques manufacturers would apply and in what order. Some vehicle manufacturers might need to commit additional resources to existing, redeveloped, or new production facilities to meet the standards. Such short-term uses of resources by vehicle manufacturers to meet the proposed standards would enable the long-term reduction of national energy consumption and could enhance long-term national productivity. For further discussion of the costs and benefits of the proposed rule, consult NHTSA's Preliminary Regulatory Impact Analysis.

7.9 Irreversible and Irretrievable Commitments of Resources

As noted above, some vehicle manufacturers might need to commit additional resources to existing, redeveloped, or new production facilities to meet the standards. In some cases, this could represent an irreversible and irretrievable commitment of resources. The specific amounts and types of irretrievable resources (such as electricity and other energy consumption) that manufacturers would expend in meeting the proposed standards would depend on the methods and technologies manufacturers select. However, the societal costs of the commitment of resources by manufacturers to comply with the proposed CAFE standards would likely be offset by fuel savings generated from implementing the standards.

CHAPTER 8 MITIGATION

CEQ regulations implementing NEPA require that the discussion of alternatives in an EIS "[i]nclude appropriate mitigation measures not already included in the proposed action or alternatives" 40 CFR § 1502.14(f). An EIS should discuss the "[m]eans to mitigate adverse environmental impacts" 40 CFR § 1502.16(h). As defined in the CEQ regulations, mitigation includes (40 CFR § 1508.20):

- Avoiding the impact altogether by not taking a certain action or parts of an action
- Minimizing impacts by limiting the degree or magnitude of the action and its implementation
- Rectifying the impact by repairing, rehabilitating, or restoring the affected environment
- Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action
- Compensating for the impact by replacing or providing substitute resources or environments

Under NEPA, an agency does not have to formulate and adopt a complete mitigation plan[1] but should analyze possible measures that could be adopted. Generally, an agency does not propose mitigation measures for an action resulting in beneficial effects.

8.1 Overview of Impacts

Emissions of criteria and hazardous air pollutants are generally anticipated to decline. As illustrated in Chapter 4, emissions of some pollutants would increase under some action alternatives and for some analysis years, while emissions of most pollutants would decline compared to the No Action Alternative. Under the No Action Alternative, neither NHTSA nor EPA would issue a rule regarding fuel economy improvement or GHG emissions for MYs 2017–2025. Health effects are estimated to be reduced, and monetized health benefits would occur under all action alternatives.

Nationwide emissions of particulate matter, volatile organic compounds (VOCs), and benzene, would decrease under all action alternatives for all analysis years, compared to the No Action Alternative. Therefore, any negative health impacts associated with these emissions are similarly expected to be reduced.

Nationwide emissions of carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), acetaldehyde, acrolein, 1,3-butadiene, diesel particulate matter, and formaldehyde could increase under certain alternatives and analysis years. Increases in emissions of all pollutants could occur under certain action alternatives and analysis years in some nonattainment areas due to increases in VMT and electric power production. These increases would represent a slight decline in the rate of reduction otherwise achieved by implementation of Clean Air Act (CAA) standards. The potential for harm depends on the selection of the final CAFE standards, the magnitude of the emissions increases, and other factors.

[1] *Northern Alaska Environmental Center v. Kempthorne*, 457 F.3d 969, 979 (citing *Robertson,* 490 U.S. at 352 (noting that NEPA does not contain a substantive requirement that a complete mitigation plan be actually formulated and adopted)). *See* also *Valley Community Preservation Com'n v. Mineta*, 231 F. Supp. 2d 23, 41 (D.D.C. 2002) (noting that NEPA does not require that a complete mitigation plan be formulated and incorporated into an EIS).

Compared to the No Action Alternative, each of the three action alternatives would reduce fuel consumption and GHG emissions. The action alternatives would reduce the impacts of climate change that would otherwise occur under the No Action Alternative.

8.2 Mitigation Measures

Some increases in criteria and hazardous air pollutant emissions could occur as a result of implementation of the proposed standards. Notably, however, even if emissions of some pollutants show some level of increase, the associated harm might not increase concomitantly. As described in Chapter 4, ambient levels of most pollutants are trending generally downward, owing to the success of regulations governing fuel composition and vehicle emissions as well as stationary sources of emissions. Also, vehicle manufacturers can choose from a suite of technology options to reach the proposed standards, and some technology choices result in higher or lower impacts for these emissions.

Federal funds administered by the Federal Highway Administration (FHWA) could be available to help fund transportation projects to reduce emissions. FHWA provides funding to states and localities specifically to improve air quality under the Congestion Mitigation and Air Quality Improvement (CMAQ) Program. FHWA and the Federal Transit Administration (FTA) also provide funding to states and localities under other programs that have multiple objectives, including air quality improvement. For example, the Surface Transportation Program provides flexible funding that states may use for selected projects that could reduce emissions. As state and local agencies conduct their review process and recognize the need to reduce emissions of criteria pollutants such as ozone, carbon monoxide, and particulate matter, they can consider using CMAQ funds to help reduce these impacts. Further, EPA has the authority to continue to improve standards for vehicle emissions, including criteria air pollutants and hazardous air pollutants under the CAA, which could result in future reductions as EPA promulgates new regulations. Under the CAA, EPA also has the authority to regulate stationary sources of air pollution, and GHG emissions (e.g., factories and utilities) (EPA 2011i).

Each action alternative would reduce energy consumption and GHG emissions from their levels under the No Action Alternative, resulting in a net beneficial effect. Nonetheless, passenger cars and light trucks are a major contributor to energy consumption, air pollution and GHG emissions in the United States. The Federal Government is involved in a number of actions which, together with the Proposed Action, will help reduce GHG emissions from the U.S. transportation sector.

For example, in a joint NHTSA and EPA rulemaking published in September of 2011,[2] NHTSA and EPA established the first national program to improve fuel efficiency and reduce GHG emissions of heavy-duty trucks and buses. The agencies estimate that the combined standards will save approximately 530 million barrels of oil and reduce GHG emissions by approximately 270 million metric tons over the life of vehicles built for the 2014 to 2018 model years. Another example is EPA's collaboration with the freight industry through the Smartway Transport Partnership. Launched in 2004, the program provides incentives to the freight industry for improved supply-chain fuel efficiency through several components, including identification of available technologies and benchmarking. As of 2010, Smartway Partners report saving 50 million barrels of fuel and eliminating 16.5 million metric tons of CO_2 (EPA2011j).

[2] Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, 76 FR 57106 (September 15, 2011).

Further promoting the efforts to reduce fuel consumption, the Federal Aviation Administration is a sponsor of the Commercial Aviation Fuels Initiative, a coalition of the U.S. commercial aviation community that acts as a focal point for engaging the emerging alternative fuels industry (FAA 2009). The initiative seeks to enhance energy security by promoting the development of alternative fuel options for use in aviation, thereby potentially reducing impacts on GHG emissions in the transportation sector.

The U.S. Department of Energy (DOE) is involved in a number of initiatives which aim to reduce fuel consumption. For example, DOE administers the Vehicle Technologies Program, which creates public-private partnerships that enhance energy efficiency and productivity and bring clean technologies to the marketplace with the potential to reduce GHG emissions (DOE 2011b). Under the American Recovery and Reinvestment Act, DOE is currently managing grants for the development of advanced battery and electric drive components for vehicles, in addition to the purchase of plug-in hybrid and all-electric vehicles for test demonstrations. Announced in 2009, the grants amount to approximately $2.4 billion (DOE 2009a). DOE also administers programs designed to give consumers and industries information required to make environmentally conscious decisions. Specifically, the DOE Clean Cities Program develops government-industry partnerships designed to reduce petroleum consumption "by advancing the use of alternative fuels and vehicles, idle reduction technologies, hybrid electric vehicles, fuel blends, and fuel economy measures" (DOE 2009b). The focus on urbanized areas overlaps with some of the nonattainment areas identified in Chapter 4 of this EIS.

EPA is also helping to reduce petroleum consumption and GHG emissions by implementing the Renewable Fuel Standards (RFS) under CAA Section 211(o). EPA is required to determine the standard applicable to refiners, importers, and certain blenders of gasoline annually. On the basis of this standard, each obligated party determines the volume of renewable fuel that it must ensure is consumed as motor vehicle fuel. The percentage standard represents the ratio of renewable fuel volume to projected non-renewable gasoline and diesel volume. The renewable fuel standard proposed for 2012 is 9.21 percent. The current proposed standard would increase the volume of renewable fuel required to be blended into gasoline from 9 billion gallons in 2008 to 36 billion gallons by 2022. EPA estimates that the greater volumes of biofuel mandated by proposed standards would reduce GHG emissions by an annual average of 150 million tons of CO_2e equivalent.

Government wide, federal agencies are currently implementing Executive Order (EO) 13514, which sets measurable environmental performance goals for federal agencies and focuses on making improvements in their environmental, energy, and economic performance.[3] EO 13514 required each federal agency to submit a 2020 GHG emissions reduction target from its estimated 2008 baseline to CEQ and to the Office of Management and Budget by January 4, 2010. On January 29, 2010, President Obama announced that the Federal Government will reduce its GHG emissions from direct sources (e.g., lighting, heating, vehicle fuel, and federal projects) by 28 percent by 2020 (White House 2010c). This federal target is the aggregate of 35 federal agency self-reported targets. On July 20, 2010, this target was complemented by an additional target of 13 percent reduction in GHG emissions from indirect sources (e.g., employee travel and commuting) (White House 2010d). The Federal Government is the single largest energy consumer in the U.S. economy, and the White House estimates that achieving the federal agency GHG emissions reduction target will reduce federal energy use by the

[3] Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance,* 74 FR 52117 (Oct. 8, 2009).

equivalent of 646 trillion British thermal units, equal to 205 million barrels of oil, and taking 17 million cars off the road for one year (White House 2010c).

8.3 Conclusion

Although emissions of criteria and hazardous air pollutants are generally anticipated to decline, emissions of some pollutants would increase under some alternatives and for some analysis years. Several federal programs are in place to help reduce these emissions. Regarding energy consumption and climate change, the initiatives and programs discussed in this chapter illustrate an existing and continuing trend of U.S. and global awareness, emphasis, and efforts toward reducing energy consumption and GHG emissions.

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CHAPTER 10 INDEX

CHAPTER 11 DISTRIBUTION LIST

CEQ NEPA implementing regulations (40 CFR 1501.19) specify requirements for circulating an EIS. In accordance with those requirements, NHTSA is mailing this EIS to the agencies, officials, and other interested persons listed in this chapter.

11.1 Federal Agencies

- Access Board, Office of the General Counsel
- Advisory Council on Historic Preservation
- Argonne National Laboratory
- Armed Forces Retirement Home
- Board of Governors of the Federal Reserve System, Engineering and Facilities
- Committee for Purchase From People Who Are Blind or Severely Disabled,
- Consumer Product Safety Commission, Directorate for Economic Analysis
- Delaware River Basin Commission
- Denali Commission
- Executive Office of the President, Council on Environmental Quality
- Executive Office of the President, Office of Science and Technology Policy
- Export-Import Bank of the United States, Office of the General Counsel
- Farm Credit Administration, Office of Regulatory Policy
- Federal Communications Commission, Administrative Law Division
- Federal Communications Commission, Mass Media Bureau
- Federal Communications Commission, Wireless Telecommunications Bureau
- Federal Deposit Insurance Corporation, Facilities Operations Section
- Federal Energy Regulatory Commission, Division of Environmental and Engineering Review, Office of Energy Projects
- Federal Energy Regulatory Commission, Office of External Affairs
- Federal Energy Regulatory Commission, Office of Pipeline Regulation
- Federal Maritime Commission, Office of the Chairman
- Federal Trade Commission, Litigation
- General Services Administration, Public Buildings Service, Office of Applied Science
- Government of Canada, The Department of Natural Resources, Natural Resources Canada
- International Boundary and Water Commission, U.S. & Mexico, Engineering Department, United States Section
- Marine Mammal Commission
- Millennium Challenge Corporation
- National Aeronautics and Space Administration, Environmnetal Management Division
- National Capital Planning Commission, Office of Urban Design and Plan Review
- National Credit Union Administration, Office of General Counsel, Division of Operations
- National Endowment for the Arts

- National Indian Gaming Commission, Contracts Division
- National Institutes of Health, Division of Environmental Protection
- National Science Foundation, Office of the General Counsel
- Nuclear Regulatory Commission, Division of Intergovernmental Liaison and Rulemaking
- Oak Ridge National Laboratory
- Office of the Federal Coordinator, Alaska Natural Gas Transportation Projects
- Overseas Private Investment Corporation, Environmental Affairs Department
- Presidio Trust
- Securities and Exchange Commission, Office of Public Utility Regulation
- Small Business Administration, Office of Management & Administration - Office of the Associate Administrator
- Social Security Administration
- Susquehanna River Basin Commission
- Tennessee Valley Authority, Environmental Policy and Planning
- U.S. Agency for International Development
- U.S. Department of Agriculture, Agriculture Research Service, Natural Resources and Sustainable Agricultural Systems
- U.S. Department of Agriculture, Animal and Plant Health Inspection Service - Environmental Services
- U.S. Department of Agriculture, Farm Service Agency
- U.S. Department of Agriculture, National Institute of Food and Agriculture - Natural Resources and Environmental Unit
- U.S. Department of Agriculture, Natural Resources Conservation Service - Ecological Services Division
- U.S. Department of Agriculture, Office of the Secretary
- U.S. Department of Agriculture, Rural Business Cooperative Service
- U.S. Department of Agriculture, Rural Housing Service
- U.S. Department of Agriculture, Rural Utilities Service, Engineering and Environmental Staff
- U.S. Department of Agriculture, U.S. Forest Service - Ecosystem Management Coordination
- U.S. Department of Commerce, Economic Development Administration
- U.S. Department of Commerce, National Marine Fisheries Service
- U.S. Department of Commerce, National Oceanic and Atmospheric Administration Planning and Integration Office
- U.S. Department of Commerce, National Oceanic and Atmospheric Association, Fisheries Service
- U.S. Department of Commerce, National Oceanic and Atmospheric Association, National Ocean Service
- U.S. Department of Commerce, National Oceanic and Atmospheric Association, Office of General Counsel for Fisheries
- U.S. Department of Commerce, National Oceanic and Atmospheric Association, Office of the General Counsel

- U.S. Department of Commerce, National Telecommunications and Information Administration
- U.S. Department of Commerce, Office of the Secretary
- U.S. Department of Defense, Army Corps of Engineers, Planning and Policy Division
- U.S. Department of Defense, Defense Logistics Agency; Environment, Safety and Occupational Health
- U.S. Department of Defense, Defense Threat Reduction Agency
- U.S. Department of Defense, Department of Air Force, USAF Basing and Units
- U.S. Department of Defense, Department of Army, Office of Deputy Assistant Secretary of the Army, Environment Safety and Occupational Health
- U.S. Department of Defense, Department of Navy, Office of the Deputy Assistant Secretary of the Navy (Environment)
- U.S. Department of Defense, National Guard Bureau, Office of General Counsel
- U.S. Department of Defense, Office of Deputy Undersecretary Defense (Installations and Environment)
- U.S. Department of Defense, Office of the Secretary
- U.S. Department of Defense, U.S. Army Corps of Engineers, Headquarters, Environmental Community of Practice
- U.S. Department of Defense, United States Marine Corps, Natural and Cultural Resources Division
- U.S. Department of Defense, United States Navy, Office of the Chief of Naval Operations (CNO-N45)
- U.S. Department of Energy, Bonneville Power Administration
- U.S. Department of Energy, Energy Efficiency and Renewable Energy Office of Vehicle Technologies
- U.S. Department of Energy, Office of the General Counsel - Office of NEPA Policy and Compliance
- U.S. Department of Energy, Office of the Secretary
- U.S. Department of Energy, Western Area Power Administration
- U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Office of the Director
- U.S. Department of Health and Human Services, FDA Center for Drug Evaluation and Research
- U.S. Department of Health and Human Services, FDA Center for Veterinary Medicine - Office of New Animal Drug Evaluation
- U.S. Department of Health and Human Services, FDA, Center for Food Safety and Applied Nutrition
- U.S. Department of Health and Human Services, Food and Drug Administration - Office of the Commissioner
- U.S. Department of Health and Human Services, Health Resources Services Administration, Office of Federal Assistance Management
- U.S. Department of Health and Human Services, Indian Health Service

- U.S. Department of Health and Human Services, National Institutes of Health, Division of Environmental Protection
- U.S. Department of Health and Human Services, Office for Facilities Management and Policy - Division of Programs
- U.S. Department of Health and Human Services, Office of the Secretary
- U.S. Department of Homeland Security, Federal Emergency Management Agency - Office of Environmental Planning and Historic Preservation
- U.S. Department of Homeland Security, Federal Law Enforcement Training Center
- U.S. Department of Homeland Security, Office of the Secretary
- U.S. Department of Homeland Security, Transportation Security Administration
- U.S. Department of Homeland Security, U.S. Coast Guard
- U.S. Department of Homeland Security, U.S. Customs and Border Protection - Environmental Programs Branch
- U.S. Department of Housing and Urban Development, Environmental Planning Division - Office of Environment and Energy
- U.S. Department of Housing and Urban Development, Office of the Secretary
- U.S. Department of Interior, Bureau of Indian Affairs
- U.S. Department of Interior, Bureau of Land Management - Division of Decision Support, Planning, and NEPA
- U.S. Department of Interior, Bureau of Ocean Energy Management, Environmental Assessment Branch
- U.S. Department of Interior, Bureau of Ocean Energy, Management, Regulation and Enforcement (BOEMRE)
- U.S. Department of Interior, Bureau of Reclamation - Office of Program and Policy Services - Water & Environmental Resources Office
- U.S. Department of Interior, National Park Service - Environmental Planning and Compliance Branch
- U.S. Department of Interior, Office of Environmental Policy and Compliance
- U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement
- U.S. Department of Interior, Office of the Secretary
- U.S. Department of Interior, U.S. Geological Survey - Environmental Management Branch
- U.S. Department of Interior, United States Fish and Wildlife Service
- U.S. Department of Interior, United States Geological Survey
- U.S. Department of Justice, Community Oriented Policing Services, Office of General Counsel
- U.S. Department of Justice, Drug Enforcement Administration, Civil Litigation Section
- U.S. Department of Justice, Environment and Natural Resources Division, Genearl Litigation Section
- U.S. Department of Justice, Facilities and Administration Services
- U.S. Department of Justice, Federal Bureau of Investigation
- U.S. Department of Justice, Federal Bureau of Prisons, Site Selection and Environmental Review Branch

- U.S. Department of Justice, Justice Management Division, Facilities and Administrative Services
- U.S. Department of Justice, National Institute of Justice
- U.S. Department of Justice, Office of Attorney General
- U.S. Department of Justice, Office of Justice Programs, Office of General Counsel
- U.S. Department of Labor, Employment and Training Administration, Job Corps
- U.S. Department of Labor, Mine Safety and Health Administration, Office of Standards, Regulations & Variances
- U.S. Department of Labor, Occupational Safety and Health Administration
- U.S. Department of Labor, Office of the Secretary
- U.S. Department of State, Bureau of Oceans and International Environmental and Scientific Affairs, Office of Multilateral Affairs and Sustainable Development
- U.S. Department of State, Office of the Secretary
- U.S. Department of Transportation, Federal Highway Administration, Office of Project Development and Environmental Review
- U.S. Department of Transportation, Federal Highway Administration
- U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Office of the Chief Counsel
- U.S. Department of Transportation, Federal Motor Carrier Safety Administration
- Department of Transportation, Federal Railroad Administration, Office of Policy and Development
- U.S. Department of Transportation, Federal Railroad Administration, Office of Railroad Development
- U.S. Department of Transportation, Federal Transit Administration, Office of Planning and Environment
- U.S. Department of Transportation, Office of Assistant Secretary for Transportation Policy, Office of Safety, Energy, and Environment
- U.S. Department of Transportation, Research and Innovative Technology Administration
- U.S. Department of Transportation, Saint Lawrence Seaway Development Corporation
- U.S. Department of Transportation, Surface Transportation Board, Section of Environmental Analysis
- U.S. Department of Treasury, Office of Environment, Safety, and Health
- U.S. Department of Veterans Affairs, Veterans Health Administration, Office of General Counsel
- U.S. Environmental Protection Agency, Office of Federal Activities, EIS Filing Section
- U.S. Environmental Protection Agency, Office of Transportation and Air Quality
- U.S. Institute for Environmental Conflict Resolution
- United States Agency for International Development, Bureau for Economic Growth, Agriculture, and Trade
- United States Postal Service, USPS Law Department
- Valles Caldera Trust

11.2 State And Local Government Organizations

- American Samoa Office of Grants Policy/Office of the Governor, Department of Commerce, American Samoa Government
- Arkansas Office of Intergovernmental Services, Department of Finance and Administration
- Connecticut Department of Environmental Protection, Bureau of Air Management, Planning and Standards Division
- Delaware Office of Management and Budget, Budget Development, Planning & Administration
- Department of Administration, Nevada State Clearinghouse, Coordinator/SPOC
- District of Columbia Office of the City Administrator
- Federal Assistance Clearinghouse, Missouri Office of Administration, Commissioner's Office
- Florida State Clearinghouse, Florida Dept. of Environmental Protection
- Georgia State Clearinghouse
- Grants Coordination, California State Clearinghouse, Office of Planning and Research
- Guam State Clearinghouse, Office of I Segundo na Maga'lahen Guahan, Office of the Governor
- Iowa Department of Management
- Maine State Planning Office
- Maryland State Clearinghouse for Intergovernmental Assistance
- Massachusetts Office of the Attorney General
- New Hampshire Office of Energy and Planning, Attn: Intergovernmental Review Process
- North Dakota Department of Commerce
- North Mariana Islands Office of Management and Budget, Office of the Governor
- Office of Management and Budget
- Puerto Rico Planning Board, Federal Proposals Review Office
- Rhode Island Division of Planning
- South Carolina Office of State Budget
- Southeast Michigan Council of Governments
- State of Connecticut, Department of Transportation
- The Governor's Office for Local Development
- Utah State Clearinghouse, Governor's Office of Planning and Budget Utah State
- West Virginia Development Office

11.3 Elected Officials

- The Honorable Robert Bentley, Governor of Alabama
- The Honorable Sean Parnell, Governor of Alaska
- The Honorable Togiola T.A. Tulafono, Governor of American Samoa
- The Honorable Jan Brewer, Governor of Arizona
- The Honorable Mike Beebe, Governor of Arkansas

- The Honorable Edmund G. Brown, Governor of California
- The Honorable John Hickenlooper, Governor of Colorado
- The Honorable Dan Malloy, Governor of Connecticut
- The Honorable Jack Markell, Governor of Delaware
- The Honorable Rick Scott, Governor of Florida
- The Honorable Nathan Deal, Governor of Georgia
- The Honorable Eddie Calvo, Governor of Guam
- The Honorable Neil Abercrombie, Governor of Hawaii
- The Honorable C.L. "Butch" Otter, Governor of Idaho
- The Honorable Pat Quinn, Governor of Illinois
- The Honorable Mitchell E. Daniels, Governor of Indiana
- The Honorable Terry Branstad, Governor of Iowa
- The Honorable Sam Brownback, Governor of Kansas
- The Honorable Steve Beshear, Governor of Kentucky
- The Honorable Bobby Jindal, Governor of Louisiana
- The Honorable Paul LePage, Governor of Maine
- The Honorable Martin O'Malley, Governor of Maryland
- The Honorable Deval Patrick, Governor of Massachusetts
- The Honorable Rick Snyder, Governor of Michigan
- The Honorable Mark Dayton, Governor of Minnesota
- The Honorable Haley Barbour, Governor of Mississippi
- The Honorable Jeremiah W. Nixon, Governor of Missouri
- The Honorable Brian Schweitzer, Governor of Montana
- The Honorable Dave Heineman, Governor of Nebraska
- The Honorable Brian Sandoval, Governor of Nevada
- The Honorable John Lynch, Governor of New Hampshire
- The Honorable Chris Christie, Governor of New Jersey
- The Honorable Susana Martinez, Governor of New Mexico
- The Honorable Andrew Cuomo, Governor of New York
- The Honorable Beverly Perdue, Governor of North Carolina
- The Honorable Jack Dalrymple, Governor of North Dakota
- The Honorable John Kasich, Governor of Ohio
- The Honorable Mary Fallin, Governor of Oklahoma
- The Honorable John Kitzhaber, Governor of Oregon
- The Honorable Tom Corbett, Governor of Pennsylvania
- The Honorable Luis G. Fortuño, Governor of Puerto Rico
- The Honorable Lincoln Chafee, Governor of Rhode Island
- The Honorable Nikki R. Haley, Governor of South Carolina
- The Honorable Dennis Daugaard, Governor of South Dakota

- The Honorable Bill Haslam, Governor of Tennessee
- The Honorable Rick Perry, Governor of Texas
- The Honorable Benigno R. Fitial, Governor of the Commonwealth of the Northern Mariana Islands
- The Honorable John P. deJongh, Jr., Governor of the United States Virgin Islands
- The Honorable Gary Herbert, Governor of Utah
- The Honorable Peter Shumlin, Governor of Vermont
- The Honorable Bob McDonnell, Governor of Virginia
- The Honorable Chris Gregoire, Governor of Washington
- The Honorable Earl Ray Tomblin, Governor of West Virginia
- The Honorable Scott Walker, Governor of Wisconsin
- The Honorable Matthew Mead, Governor of Wyoming
- The Honorable Vincent C. Gray, Mayor of the District of Columbia

11.4 Native American Tribes

- Absentee-Shawnee Tribe of Indians of Oklahoma
- Agdaagux Tribe of King Cove
- Agua Caliente Band of Cahuilla Indians
- Ahtna, Inc.
- Ak Chin Indian Community
- Akiachak Native Community (Indian Reorganization Act [IRA])
- Akiak Native Community (IRA)
- Alabama-Coushatta Tribes of Texas
- Alabama-Quassarte Tribal Town
- Alatna Village
- Aleut Community of St. Paul Island
- Aleut Corporation
- Algaaciq Native Village (St. Mary's)
- Allakaket Village
- Alturas Indian Rancheria
- Angoon Community Association (IRA)
- Anvik Village
- Apache Tribe of Oklahoma
- Arapahoe Tribe
- Arctic Slope Regional Corp.
- Arctic Village Council
- Aroostook Band of Micmac Indians
- Asa'carsarmiut Tribe
- Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation

- Atqasuk Village
- Augustine Band of Cahuilla Indians
- Bad River Band of Lake Superior Tribe of Chippewa Indians
- Barona Band of Mission Indians
- Battle Mountain Band Council
- Bay Mills Indian Community
- Bear River Band of Rohnerville Rancheria
- Beaver Village Council
- Bering Straits Native Corp.
- Berry Creek Rancheria of Maidu Indians
- Big Lagoon Rancheria
- Big Pine Paiute Tribe of the Owens Valley Paiute Shoshone Indians
- Big Sandy Rancheria of Mono Indians
- Big Valley Rancheria of Pomo Indians
- Birch Creek Tribal Council
- Bishop Paiute Tribe
- Blackfeet Tribe of the Blackfeet Indian
- Blue Lake Rancheria
- Board of Directors, Trenton Indian Service Area
- Bois Forte Reservation Business Committee
- Bridgeport Indian Colony
- Bristol Bay Native Corp.
- Buena Vista Rancheria of Me-wuk Indians
- Burns Paiute Tribe of the Burns Paiute Indian Colony
- Cabazon Band of Mission Indians
- Cachil DeHe Band of Wintun Indians (Colusa Rancheria)
- Caddo Nation of Oklahoma
- Cahto Indian Tribe of Laytonville Rancheria
- Cahuilla Band of Mission Indians
- California Valley Miwok Tribe
- Calista Corporation
- Campo Band of Diegueno Mission Indians
- Carson Community Council
- Catawba Indian Nation
- Cayuga Nation of New York
- Cedarville Rancheria
- Central Council Tlingit & Haida Indian Tribes of Alaska
- Chalkyitsik Village
- Cheesh-Na Tribal Council

- Chemehuevi Indian Tribe
- Chenega IRA Council
- Cher-Ae Heights Indian Community of the Trinidad Rancheria
- Cherokee Nation
- Chevak Native Village
- Cheyenne River Sioux Tribe
- Cheyenne-Aprapaho Tribes
- Chickaloon Native Village
- Chickasaw Nation
- Chicken Ranch Rancheria of Me-wuk Indians
- Chignik Lagoon Council
- Chignik Lake Village Council
- Chilkat Indian Village (Klukwan) (IRA)
- Chilkoot Indian Association (IRA)
- Chinik Eskimo Community
- Chippewa-Cree Indians
- Chitimacha Tribe of Louisiana
- Chitina Traditional Indian Village Council
- Choctaw Nation of Oklahoma
- Chugach Alaska Corp.
- Chuloonawick Native Village
- Circle Native Community (IRA)
- Citizen Potawatomi Nation
- Cloverdale Rancheria of Pomo Indians
- Cocopah Tribe of Arizona
- Coeur D'Alene Tribe
- Cold Springs Rancheria of Mono Indians
- Colorado River Indian Tribe
- Comanche Nation
- Confederated Salish & Kootenai Tribes of the Flathead Reservation
- Confederated Tribes and Bands of the Yakama Nation
- Confederated Tribes of Coos, Lower Umpqua and Siuslaw Indians
- Confederated Tribes of Siletz Indians of Oregon
- Confederated Tribes of the Chehalis Reservation
- Confederated Tribes of the Colville Reservation
- Confederated Tribes of the Goshute Reservation, Nevada and Utah
- Confederated Tribes of the Grand Ronde Community of Oregon
- Confederated Tribes of the Umatilla Indian Reservation
- Confederated Tribes of the Warm Springs Reservation

- Cook Inlet Region, Inc.
- Coquille Tribe of Oregon
- Cortina Indian Rancheria of Wintun Indians
- Coushatta Tribe of Louisiana
- Cow Creek Band of Umpqua Indians
- Cowlitz Indian Tribe
- Coyote Valley Band of Pomo Indians
- Craig Community Association (IRA)
- Crow Creek Sioux Tribe
- Crow Tribe of Montana
- Curyung Tribal Council
- Delaware Nation
- Delaware Tribe of Indians
- Douglas Indian Association (IRA)
- Doyon Ltd.
- Dresslerville Colony (Washoe Tribe of Nevada & California)
- Dry Creek Rancheria of Pomo Indians
- Duckwater Shoshone Tribe
- Eastern Band of Cherokee Indians
- Eastern Shawnee Tribe of Oklahoma
- Egegik Village
- Eklutna Native Village
- Ekwok Village
- Elem Indian Colony of Pomo Indians of the Sulphur Bank Rancheria
- Elim IRA Council
- Elk Valley Rancheria
- Elko Band (Te-Moak Tribe of Western Shoshone Indians of Nevada)
- Ely Shoshone Tribe of Nevada
- Emmonak Village
- Enterprise Rancheria of Maidu Indians
- Evansville Village
- Ewiiaapaayp Band of Kumeyaay Indians
- Fallon Paiute Shoshone Tribal Business Council
- Federated Indians of Graton Rancheria
- Flandreau Santee Sioux Tribe of South Dakota
- Fond du Lac Reservation Business Committee
- Forest County Potawatomi Community
- Fort Belknap Indian Community
- Fort Bidwell Indian Community

- Fort Independence Indian Community of Paiute Indians
- Fort McDermitt Paiute and Shoshone Tribes of Fort McDermitt Indian Reservation
- Fort McDowell Yavapai Nation
- Fort Mojave Indian Tribe of Arizona, California & Nevada
- Fort Sill Apache Tribe of Oklahoma
- Gambell IRA Council
- Gila River Indian Community
- Grand Portage Band (Minnesota Chippewa Tribe)
- Grand Traverse Band of Ottawa and Chippewa Indians
- Greenville Rancheria of Maidu Indians
- Grindstone Rancheria of Wintun-Wailaki Indians
- Guidiville Rancheria of California
- Gulkana Village
- Habematolel Pomo of Upper Lake
- Hannahville Indian Community
- Havasupai Tribe
- Healy Lake Village
- Ho-Chunk Nation of Wisconsin
- Hoh Indian Tribe
- Holy Cross Village
- Hoonah Indian Association (IRA)
- Hoopa Valley Tribe
- Hopi Tribe of Arizona
- Hopland Band of Pomo Indians
- Houlton Band of Maliseet Indians
- Hualapai Indian Tribe
- Hughes Village
- Huslia Village Council
- Hydaburg Cooperative Assn. (IRA)
- Igiugig Village
- Iipay Nation of Santa Ysabel
- Inaja Band of Diegueno Mission Indians of the Inaja and Cosmit Reservation
- Inupiat Community of Arctic Slope (IRA)
- Ione Band of Miwok Indians
- Iowa Tribe of Kansas & Nebraska
- Iowa Tribe of Oklahoma
- Iqurmiut Traditonal Council
- Jackson Rancheria of Me-Wuk Indians
- Jamestown S'Klallam Tribe of Washington

- Jamul Indian Village of California
- Jena Band of Choctaw Indians
- Jicarilla Apache Nation
- Kaguyak Village
- Kaibab Band of Paiute Indians of the Kaibab Indian Reservation
- Kaktovik Village
- Kalispel Indian Community of Kalispel Reservation
- Kaltag Tribal Council
- Karuk Tribe of California
- Kashia Band of Pomo Indians of the Stewarts Point Rancheria
- Kaw Nation
- Kenaitze Indian Tribe (IRA)
- Ketchikan Indian Community Tribal Council
- Keweenaw Bay Indian Community
- Kialegee Tribal Town
- Kickapoo Traditional Tribe of Texas
- Kickapoo Tribe of Indians of the Kickapoo Reservation in Kansas
- Kickapoo Tribe of Oklahoma
- King Island Native Community (IRA)
- King Salmon Tribe
- Kiowa Indian Tribe of Oklahoma
- Klamath Tribe
- Klawock Cooperative Association
- Knik Village
- Kobuk Traditional Council
- Kokhanok Village
- Kongiganak Traditional Council
- Koniag, Inc.
- Kootenai Tribe of Idaho
- Koyukuk Native Village
- La Jolla Band of Luiseno Mission Indians of the La Jolla Reservation
- La Posta Band of Diegueno Mission Indians of the La Posta Indian Reservation
- Lac Courte Oreilles Band of Lake Superior Chippewa Indians of Wisconsin
- Lac du Flambeau Band of Lake Superior Chippewa Indians of Wisconsin
- Lac Vieux Desert Band of Lake Superior Chippewa Indians
- Larsen Bay Tribal Council
- Las Vegas Tribe of Paiute Indians of the Las Vegas Indian Colony
- Leech Lake Band (Minnesota Chippewa Tribe)
- Lesnoi Village

- Levelock Village
- Lime Village Traditional Council (LVTC)
- Little River Band of Ottawa Indians
- Little Traverse Bay Bands of Odawa Indians
- Los Coyotes Band of Cahuilla & Cupeno Indians
- Louden Tribal Council
- Lovelock Paiute Tribe of the Lovelock Indian Colony
- Lower Brule Sioux Tribe
- Lower Elwha Tribal Community
- Lower Lake Rancheria
- Lower Sioux Indian Community in the State of Minnesota
- Lummi Tribe
- Lytton Rancheria of California
- Makah Indian Tribe
- Manchester Band of Pomo Indians of the Manchester-Point Arena Rancheria
- Manley Hot Springs Village
- Manokotak Village
- Manzanita Band of Diegueno Mission Indians
- Mary's Igloo Traditional Council
- Mashantucket Pequot Tribe of Connecticut
- Mashpee Wampanoag Tribal Council
- Match-e-be-nash-she-wish Band of Pottawatomi Indians of Michigan
- McGrath Native Village Council
- Mechoopda Indian Tribe of Chico Rancheria
- Menominee Indian Tribe of Wisconsin
- Mentasta Lake Tribal Council
- Mesa Grande Band of Diegueno Mission Indians
- Mescalero Apache Tribe
- Metlakatla Indian Community
- Miami Tribe of Oklahoma
- Miccosukee Indian Tribe of Florida
- Middletown Rancheria of Pomo Indians of California
- Mille Lacs Band Assembly
- Minnesota Chippewa Tribe
- Mississippi Band of Choctaw Indians
- Moapa Band of Paiute Indians
- Modoc Tribe of Oklahoma
- Mohegan Indian Tribe of Connecticut
- Mooretown Rancheria of Maidu Indians of California

- Morongo Band of Mission Indians
- Muckleshoot Indian Tribe
- Muscogee (Creek) Nation
- Naknek Native Village
- Nana Corporation
- Narragansett Indian Tribe of Rhode Island
- Native Village of Afognak
- Native Village of Akhiok
- Native Village of Akutan
- Native Village of Aleknagik
- Native Village of Ambler
- Native Village of Atka
- Native Village of Barrow Inupiat Traditional Government
- Native Village of Belkofski
- Native Village of Bill Moore's Slough
- Native Village of Brevig Mission
- Native Village of Buckland (IRA)
- Native Village of Cantwell
- Native Village of Chuathbaluk
- Native Village of Council
- Native Village of Crooked Creek
- Native Village of Deering (IRA)
- Native Village of Diomede (IRA) (aka Inalik)
- Native Village of Eagle (IRA)
- Native Village of Eek
- Native Village of Ekuk
- Native Village of Eyak
- Native Village of False Pass
- Native Village of Fort Yukon (IRA)
- Native Village of Gakona
- Native Village of Georgetown
- Native Village of Goodnews Bay
- Native Village of Hamilton
- Native Village of Hooper Bay
- Native Village of Kanatak (IRA)
- Native Village of Karluk (IRA)
- Native Village of Kasigluk
- Native Village of Kiana
- Native Village of Kipnuk

- Native Village of Kivalina (IRA)
- Native Village of Kluti-Kaah (aka Copper Center)
- Native Village of Kotzebue (IRA)
- Native Village of Koyuk (IRA)
- Native Village of Kwigillingok
- Native Village of Kwinhagak (IRA)
- Native Village of Marshall
- Native Village of Mekoryuk (IRA)
- Native Village of Minto (IRA)
- Native Village of Nanwalek (aka English Bay)
- Native Village of Napaimute
- Native Village of Napakiak (IRA)
- Native Village of Napaskiak
- Native Village of Nikolski (IRA)
- Native Village of Noatak (IRA)
- Native Village of Nuiqsut
- Native Village of Nunam Iqua
- Native Village of Nunapitchuk (IRA)
- Native Village of Ouzinkie
- Native Village of Paimiut
- Native Village of Paimiut
- Native Village of Perryville Tribal Council
- Native Village of Pitka's Point
- Native Village of Point Hope (IRA)
- Native Village of Point Lay (IRA)
- Native Village of Port Heiden
- Native Village of Port Lions
- Native Village of Savoonga (IRA)
- Native Village of Shaktoolik (IRA)
- Native Village of Shishmaref (IRA)
- Native Village of Shungnak (IRA)
- Native Village of South Naknek
- Native Village of St. Michael (IRA)
- Native Village of Stevens (IRA)
- Native Village of Tanana (IRA)
- Native Village of Tatitlek (IRA)
- Native Village of Tazlina
- Native Village of Tetlin (IRA)
- Native Village of Tyonek (IRA)

- Native Village of Unalakleet (IRA)
- Native Village of Venetie Tribal Government (IRA)
- Native Village of Wales (IRA)
- Native Village of White Mountain (IRA)
- Navajo Nation
- Nelson Lagoon Tribal Council
- Nenana Native Association
- New Koliganek Village Council
- New Stuyahok Village
- Newhalen Village
- Newtok Traditional Council
- Nez Perce Tribe
- Nightmute Traditional Council
- Nikolai Village
- Ninilchik Traditional Council
- Nisqually Indian Tribe
- Nome Eskimo Community
- Nondalton Village
- Nooksack Indian Tribe of Washington
- Noorvik Native Community (IRA)
- Northern Cheyenne Tribe
- Northfork Rancheria of Mono Indians of California
- Northway Village
- Northwestern Band of Shoshoni Nation of Utah (Washakie)
- Nottawaseppi Huron Band of Pottawatomi
- Nulato Tribal Council
- Nunakauyarmiut Tribe
- Oglala Sioux Tribe
- Ohkay Owingeh
- Ohogamuit Traditional Council
- Omaha Tribe of Nebraska
- Oneida Nation of New York
- Oneida Tribe of Indians of Wisconsin
- Onondaga Nation of New York
- Organized Village of Grayling (IRA)
- Organized Village of Kake (IRA)
- Organized Village of Kasaan (IRA)
- Organized Village of Kwethluk (IRA)
- Organized Village of Saxman (IRA)

- Orutsararmuit Native Council
- Osage Nation
- Oscarville Tribal Council
- Otoe-Missouria Tribe of Indians
- Ottawa Tribe of Oklahoma
- Paiute Indian Tribe of Utah
- Paiute-Shoshone Indians of the Lone Pine Community of the Lone Pine Reservation
- Pala Band of Luiseno Mission Indians
- Pascua Yaqui Tribe of Arizona
- Paskenta Band of Nomlaki Indians of California
- Passamaquoddy Tribe - Indian Township Reservation
- Passamaquoddy Tribe - Pleasant Point Reservation
- Pauloff Harbor Village
- Pauma Band of Luiseno Mission Indians of the Pauma & Yuima Reservation
- Pawnee Nation of Oklahoma
- Pechanga Band of Luiseno Mission Indians
- Pedro Bay Village Council
- Penobscot Tribe of Maine
- Peoria Tribe of Indians of Oklahoma
- Petersburg Indian Association (IRA)
- Picayune Rancheria of Chukchansi Indians of California
- Pilot Point Tribal Council
- Pilot Station Traditional Village
- Pinoleville Pomo Nation
- Pit River Tribe
- Platinum Traditional Village Council
- Poarch Band of Creek Indians of Alabama
- Pokagon Band of Potawatomi Indians
- Ponca Tribe of Indians of Oklahoma
- Ponca Tribe of Nebraska
- Port Gamble Indian Community
- Port Graham Village Council
- Portage Creek Village Council
- Potter Valley Tribe
- Prairie Band of Potawatomi Nation
- Prairie Island Indian Community in the State of Minnesota
- Pueblo of Acoma
- Pueblo of Cochiti
- Pueblo of Isleta

- Pueblo of Jemez
- Pueblo of Laguna
- Pueblo of Nambe
- Pueblo of Picuris
- Pueblo of Pojoaque
- Pueblo of San Felipe
- Pueblo of San Ildefonso
- Pueblo of Sandia
- Pueblo of Santa Ana
- Pueblo of Santa Clara
- Pueblo of Santo Domingo
- Pueblo of Taos
- Pueblo of Tesuque
- Pueblo of Zia
- Pueblo of Zuni
- Puyallup Tribe
- Pyramid Lake Paiute Tribe
- Qagan Tayagungin Tribe of Sand Point Village
- Qawalangin Tribe of Unalaska
- Quapaw Tribe of Indians
- Quartz Valley Indian Community
- Quechan Tribe
- Quileute Tribe
- Quinault Tribe
- Ramah Navajo Chapter
- Ramona Band of Cahuilla Mission Indians
- Rampart Village
- Red Cliff Band of Lake Superior Chippewa Indians of Wisconsin
- Red Lake Band of Chippewa Indians
- Redding Rancheria
- Redwood Valley Rancheria of Pomo Indians
- Reno-Sparks Indian Colony
- Resighini Rancheria
- Rincon Band of Luiseno Mission Indians
- Robinson Rancheria of Pomo Indians of California
- Rosebud Sioux Tribe
- Round Valley Indian Tribe
- Ruby Tribal Council
- Rumsey Indian Rancheria of Wintun Indians of California (Yocha Dehe Wintun Nation)

- Sac & Fox Tribe of the Mississippi in Iowa
- Sac and Fox Nation
- Sac and Fox Nation of Missouri in Kansas and Nebraska
- Saginaw Chippewa Indian Tribe of Michigan
- Saint Regis Mohawk Tribe
- Salt River Pima-Maricopa Indian Community
- Samish Indian Tribe
- San Carlos Apache Tribe
- San Juan Southern Paiute Tribe of Arizona
- San Manuel Band of Mission Indians
- San Pasqual Band of Diegueno Mission Indians of California
- Santa Rosa Band of Cahuilla Indians
- Santa Rosa Indian Community
- Santa Ynez Band of Chumash Mission Indians
- Santee Sioux Nation
- Sauk-Suiattle Indian Tribe
- Sault Ste. Marie Tribe of Chippewa Indians of Michigan
- Scammon Bay Traditional Council
- Scotts Valley Band of Pomo Indians of California
- Sealaska Corporation
- Selawik IRA Council
- Seldovia Village Tribe (IRA)
- Seminole Nation of Oklahoma
- Seminole Tribe of Florida
- Seneca Nation of New York
- Seneca-Cayuga Tribe of Oklahoma
- Shageluk Native Village (IRA)
- Shakopee Mdewakanton Sioux Community of Minnesota
- Shawnee Tribe
- Sherwood Valley Rancheria of Pomo Indians of California
- Shingle Springs Band of Miwok Indians
- Shoalwater Bay Tribe
- Shoshone Business Committee
- Shoshone-Bannock Tribes of the Fort Hall Reservation of Idaho
- Shoshone-Paiute Tribes of the Duck Valley Reservation
- Sisseton-Wahpeton Oyate of the Lake Traverse Reservation
- Sitka Tribe of Alaska (IRA)
- Skagway Village
- Skokomish Indian Tribe

- Skull Valley Band of Goshute Indians of Utah
- Sleetmute Traditional Council
- Smith River Rancheria
- Snoqualmie Tribe
- Soboba Band of Luiseno Indians
- Sokaogon Chippewa Community
- Solomon Traditional Council
- South Fork Band (Te-Moak Tribe of Western Shoshone Indians of Nevada)
- Southern Ute Indian Tribe
- Spirit Lake Tribe
- Spokane Tribe
- Squaxin Island Tribe
- St. Croix Chippewa Indians of Wisconsin
- St. George Traditional Council
- Standing Rock Sioux Tribe of North & South Dakota
- Stebbins Community Association (IRA)
- Stewart Community (Washoe Tribe of Nevada & California)
- Stillaguamish Tribe of Washington
- Stockbridge Munsee Community of Wisconsin
- Summit Lake Paiute Tribe
- Sun'aq Tribe of Kodiak
- Suquamish Indian Tribe
- Susanville Indian Rancheria
- Swinomish Indians of the Swinomish Reservation
- Sycuan Band of the Kumeyaay Nation
- Table Mountain Rancheria of California
- Takotna Village
- Tanacross Village Council
- Telida Village
- Teller Traditional Council
- Te-Moak Tribe of Western Shoshone Indians of Nevada
- Thlopthlocco Tribal Town
- Three Affiliated Tribe
- Timbi-sha Shoshone Tribe
- Tohono O'odham Nation of Arizona
- Tonawanda Band of Seneca Indians of New York
- Tonkawa Tribe of Indians of Oklahoma
- Tonto Apache Tribe of Arizona
- Torres Martinez Desert Cahuilla Indians

- Traditional Village of Togiak
- Tulalip Tribes of the Tulalip Reservation
- Tule River Indian Tribe
- Tuluksak Native Community (IRA)
- Tunica-Biloxi Indian Tribe of Louisiana
- Tuntutuliak Traditional Council
- Tununak IRA Council
- Tuolumne Band of Me-Wuck Indians
- Turtle Mountain Band of Chippewa Indians of North Dakota
- Tuscarora Nation of New York
- Twenty-Nine Palms Band of Mission Indians of California
- Twin Hills Village Council
- Ugashik Traditional Village Council
- Umkumiut Native Village
- Unga Tribal Council
- United Auburn Indian Community of the Auburn Rancheria of California
- United Keetoowah Band of Cherokee Indians in Oklahoma
- Upper Sioux Community
- Upper Skagit Indian Tribe
- Ute Business Committee
- Ute Mountain Ute Tribe
- Utu Utu Gwaitu Paiute Tribe of the Benton Paiute
- Venetie Village Council
- Viejas Band of Capitan Grande Band of Mission Indians of the Viejas Reservation
- Village of Alakanuk
- Village of Anaktuvuk Pass
- Village of Aniak
- Village of Atmautluak
- Village of Chefornak
- Village of Clarks Point
- Village of Dot Lake
- Village of Iliamna
- Village of Kalskag
- Village of Kotlik
- Village of Lower Kalskag
- Village of Old Harbor
- Village of Red Devil
- Village of Salamatoff
- Village of Stony River

- Village of Wainwright
- Walker River Paiute Tribe
- Wanpanoag Tribe of Gay Head (Aquinnah) of Massachusetts
- Washoe Tribe of Nevada and California
- Wells Indian Colony Band Council
- White Earth Band (Minnesota Chippewa Tribe)
- White Mountain Apache Tribe
- Wichita and Affiliated Tribes
- Wilton Rancheria
- Winnebago Tribe of Nebraska
- Winnemucca Indian Colony of Nevada
- Wiyot Tribe
- Woodfords Community (Washoe Tribe of Nevada & California)
- Wrangell Cooperative Association (IRA)
- Wyandotte Nation
- Yakutat Tlingit Tribe
- Yankton Sioux Tribe of South Dakota
- Yavapai-Apache Nation
- Yavapai-Prescott Tribe
- Yerington Paiute Tribe
- Yomba Shoshone Tribe
- Ysleta Del Sur Pueblo of Texas
- Yupiit of Andreafski
- Yurok Tribe

11.5 Stakeholders

- AAA Mid-Atlantic, Public and Government Relations
- Alaska Public Interest Research Group
- Alliance of Automobile Manufacturers, Environmental Affairs
- Alliance to Save Energy
- Aluminum Association
- American Association of Blacks in Energy
- American Automotive Policy Council
- American Chemistry Council, Plastics
- American Council for an Energy Efficient Economy
- American Gas Association
- American Indian Science and Engineering Society
- American International Automobile Dealers Association
- American Jewish Committee

- American Lung Association
- American Natural Gas Alliance
- American Powersports Mfg. Co. Inc.
- American Road & Transportation Builders Association (ARTBA)
- American Suzuki Motor Corporation, President
- Appalachian Mountain Club
- Arizona Public Interest Research Group
- Association of International Automobile Manufacturers, Inc.
- Association of Metropolitan Planning Organizations
- Auto Research Center, LLC
- Better Place, North America Market Development
- BlueGreen Alliance
- BMW of North America, LLC, President
- Border Valley Trading, LTD
- Bridgestone Americas Tire Operations Product Development Group, Techincal Standards and Regulations
- California Air Pollution Control Officers Association
- CALPIRG (Public Interest Research Group)
- CALSTART
- Center for Auto Safety
- Center for Biological Diversity, Climate Law Institute
- Central States Air Resources Agencies
- Ceres and the Investor Network on Climate Risk (INCR)
- Chrysler Group, LLC, Vice President, Regulatory Affairs
- Citizens' Utility Board of Oregon
- Clean Air Task Force
- Clean Energy
- Columbian Justice Peace and Integrity of Creation Office
- Commission for Environmental Cooperation
- Competitive Enterprise Institute
- Conservation Law Foundation
- Consumer Action
- Consumer Assistance Council of Cape Cod
- Consumer Federation of America
- Consumer Federation of the Southeast
- Consumers for Auto Reliability and Safety
- Consumers Union
- Con-way Inc
- Coulomb Technologies, Inc.

- Criterion Economics, LLC
- Crowell Moring
- Daimler AG, c/o President, Mercedes-Benz USA, LLC
- Daimler Vans USA, LLC
- Dale Kardos & Associates, Inc.
- Dana Holding Corporation
- Defenders of Wildlife
- Democratic Processes Center
- Ecology Center
- Electric Power Research Institute, Electric Transportation & Energy Storage
- Empire State Consumer Association
- Engine Manufacturers Association
- Environment America
- Environment Illinois
- Environmental Defense Fund
- ETEC
- Evangelical Environmental Network, Climate Campaign
- Evangelical Lutheran Church in America
- FedEx Corporation
- Florida Consumer Action Network
- Florida Power & Light Co.
- Florida Public Interest Research Group
- Ford Motor Company, Group Vice President, Sustainability, Environment and Safety Engineering
- Friends Committee on National Legislation
- General Motors, Vice President, Environment, Energy and Safety Policy
- Gibson, Dunn & Crutcher LLP
- Greater Washington Interfaith Power and Light c/o Interfaith Conference of Metropolitan Washington
- HayDay Farms, Inc
- Honda North America, Inc., Vice President, Government and Industry Relations
- Hyundai Kia America Technical Center Inc. (HATCI), Regulation & Certification Department
- Illinois Trucking Association
- Illnois Public Interest Research Group
- Insurance Institute for Highway Safety, VRC Operations
- International Council on Clean Transportation
- Jaguar Land Rover North America LLC, President
- Jewish Community Relations Council
- Justice and Witness Ministries
- Kirkland & Ellis, LLP

- Mack and Volvo Trucks
- Maryknoll Office of Global Concerns
- Maryland Consumer Rights Coalition
- Maryland Public Interest Research Group
- Massachusetts Consumers Council
- Massachussetts Public Interest Research Group, Transportation
- Mazda North American Operations, Director, Government & Public Affairs
- Mercatus Center, George Mason University
- Metro 4, Inc. - Southeastern States Air Resource Managers, Inc.,
- Michelin North America, Inc., President
- Michigan Tech University, ME-EM Department
- Mid-Atlantic Regional Air Management Association, Inc.,
- Mitsubishi Motors North America, Inc., Director and General Manager, Regulatory Affairs and Certification
- National Association of Attorneys General
- National Association of Clean Air Agencies (NACAA), NACAA Mobile Sources and Fuels Committee (Massachussetts)
- National Association of Counties
- National Association of Regional Councils
- National Association of Regulatory Utility Commissioners
- National Association of State Energy Officials
- National Automobile Dealers Association
- National Caucus of Environmental Legislators
- National Conference of State Legislatures
- National Council of Churches USA
- National Governors Association
- National Groundwater Association
- National League of Cities
- National Truck Equipment Association
- National Wildlife Federation, National Advocacy Center
- Natural Gas Vehicles (NGV) America,
- Natural Resources Canada
- Natural Resources Defense Council, Climate Center
- New Jersey Citizen Action
- New Mexico Public Interest Research Group,
- Nissan North America, Inc., Director, Government Affairs
- NY Public Interest Research Group
- Ozone Transport Commission
- Pew Environment Group, Climate and Energy Programs
- Pierobon & Partners

- Podesta GROUP
- Pollution Probe
- Porsche Cars North America, Inc., Regulatory Affairs
- Presbyterian Church (USA)
- Public Citizen
- Recreation Vehicle Industry Association
- Republicans for Environmental Protection
- Road Safe America
- Rocky Mountain Institute
- Rubber Manufacturers Association
- Saab Cars North America, Inc., President
- Safe Climate Campaign
- Santa Clara Pueblo
- SaviCorp, Inc.
- Securing America's Future Energy
- Sentech, Inc.
- Sierra Club
- Single Springs Rancheria, Band of Miwok Indians
- Socially Responsible Investing, General Board of Pension and Health Benefits of The United Methodist Church
- Sport Utility Vehicle Owners of America
- Subaru of America, Government Relations
- SUN DAY Campaign
- Teamsters Joint Council 25
- Tesla Motors, Inc., Director of Public Policy and Associate General Counsel
- Tetlin Village Council
- The Accord Group
- The Consumer Alliance
- The Council of State Governments
- The Environmental Council of the States
- The Episcopal Church
- The Hertz Corporation
- The Lee Auto Malls
- The Pew Charitable Trusts, Pew Environment Group
- The United Methodist Church General, Board of Church and Society
- TIAX LLC
- ToChi Technologies Inc
- Toyota Motor North America, Inc., Senior Vice President, Technical and Regulatory Affairs
- Trillium Asset Management Corporation

- Truck Manufacturer's Association
- Truman Project
- Tufts University, The Fletcher School of Law and Diplomacy
- U.S. Chamber of Commerce
- U.S. Conference of Mayors
- Union for Reform Judaism
- Union of Concerned Scientists, Washington Office, Clean Vehicles Program
- United Auto Workers
- United Automobile, Aerospace and Agricultural Workers of America (UAW)
- United Church of Christ
- University of Colorado School of Law
- University of Michigan Transportation Research Institute
- US Public Interest Research Group
- Utility Consumers Action Network
- Vermont Public Interest Research Group
- Victims Committee for Recall of Defective Vehicles
- Virginia Citizens Consumer Council
- Volkswagen Group of America, Inc., Executive Vice President, Public Affairs & General Counsel
- Volvo Group North America, Vice President, Government and Industry Relations
- West Virginia University
- Western Governors' Association
- Western Regional Air Partnership
- Western States Air Resources Council
- Wisconsin Consumers League

CHAPTER 12 PREPARERS

12.1 National Highway Traffic Safety Administration

Name/Role	Qualifications/Experience
PREPARERS	
Angel Jackson, Contracting Officer's Technical Representative	
	J.D., University of Cincinnati College of Law; M.S., Mechanical Engineering; B.S., Mechanical Engineering, Florida Agricultural and Mechanical University
	2 years of legal experience; 4 years of experience in regulatory analysis and drafting; 7 years of engineering experience
Carrie Gage, Attorney Advisor	
	J.D., University of Washington School of Law; B.A., Psychology, Whitman College
	3 years of legal experience; 2 years of policy/legislative experience
Russell Krupen, Attorney Advisor	
	J.D., University of California, Los Angeles School of Law; B.A., Sociology, Harvard University
	Less than 1 year of legal experience
John Wood, Attorney Advisor	
	J.D., University of Mississippi School of Law; B.B.A., Finance, Southern Methodist University
	Less than 1 year of legal experience
REVIEWERS	
John Donaldson, Assistant Chief Counsel, Legislation and General Law	
	J.D., Boston College Law School; B.A., Economics, Cornell University
	27 years of experience in vehicle safety issues, including environmental impact assessments
Don H. Pickrell, Chief Economist, John A. Volpe National Transportation Systems Center	
	Ph.D., Urban Planning; M.A., Urban Planning, University of California, Los Angeles; B.A. (with high honors), Economics and Mathematics, University of California, San Diego
	33 years of experience in applied transportation economics, including 18 years of experience in analysis of environmental impacts of transportation activity
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	M.S., Mechanical Engineering, University of Michigan; B.S., Mechanical Engineering, Pennsylvania State University
	31 years of experience in automotive engineering related to fuel economy and emissions development; 1 year of experience in vehicle fuel economy rulemaking
O. Kevin Vincent, Chief Counsel	
	J.D., University of Alabama School of Law; B.S. Electrical Engineering, University of Alabama
	25 years of legal experience in contracts and administrative law issues
Stephen P. Wood, Assistant Chief Counsel, Vehicle Safety Standards and Harmonization	
	J.D., Columbia Law School; B.A., Political Science, Williams College
	42 years of experience in vehicle safety rulemaking; 36 years of experience in fuel economy rulemaking

12.2 Consultant Team

ICF International supported the National Highway Traffic Safety Administration (NHTSA) in preparing its environmental analyses and preparing this Environmental Impact Statement (EIS).

Name/Role	Qualifications/Experience
PROJECT MANAGEMENT	
Alan Summerville, Officer in Charge	
	M.A., City Planning, University of Pennsylvania; B.A., Economics and Political Science, University of Vermont – Burlington
	20 years of experience participating in and managing the preparation of NEPA documents
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	M.S., Environmental Science and Management, Duquesne University; B.S., Environmental Studies, Bucknell University
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TECHNICAL AND OTHER EXPERTISE (alphabetically)	
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	5 years of experience assessing and analyzing climate change issues
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	11 years of experience in consulting, education, and library settings
David Ernst, Air Quality Lead	
	M.C.R.P., Environmental Policy, Harvard University; B.S., Urban Systems Engineering; B.A., Ethics and Politics, Brown University
	31 years of experience preparing air quality analysis for NEPA documents

Lizelle Espinosa, Reference Manager	
	B.S., Government Administration, Christopher Newport University
	8 years of experience in environmental consulting in the areas of environmental impact assessment, policy analysis, and regulatory compliance
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Christopher Evans, Life-cycle Assessment Analyst	
	M.Sc., Technology and Policy, Massachusetts Institute of Technology; B. Sc., Mechanical Engineering, University of Manitoba
	6 years of experience in policy analysis of climate change issues, life-cycle assessment of energy and greenhouse gas emissions
Rebecca Ferenchiak, Climate Change Analyst	
	B.S., Chemical Engineering, Villanova University
	2 years of experience in climate change and sustainability consulting
Randall Freed, Senior Climate Change Advisor	
	M.S., Water Resource Management, University of Maryland; B.S., Zoology, University of Maryland
	37 years of experience in assessing and managing environmental risk; 16 years of experience assessing climate change issues
Christopher Holder, Air Quality Analyst	
	M.S., Meteorology, North Carolina State University; B.A., Meteorology, North Carolina State University
	6 years of experience in hazardous air pollutant risk assessment, climate change impacts, greenhouse gas emission estimation, and renewable energy technologies and policy
Brad Hurley, Climate Change Analyst	
	B.A., Environmental Science, State University of New York College at Purchase
	22 years of experience in writing and editing reports, articles, Web content, and other publications on climate change and other environmental topics for a variety of audiences
Nisha Krishnan, Climate Change Analyst	
	M.A., Applied Economics, Johns Hopkins University; B.A., Economics and Political Science, Macalester College.
	5 years of experience in researching, analyzing, and designing policies and projects on international and domestic climate change impacts and adaptation.
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	B.S., Meteorology, Lyndon State College; B.A., Global Studies, Lyndon State College
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Charlotte Mack, Climate Change Analyst	
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	5 years of experience working on climate change issues
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	M.E.M., Environmental Health and Security, Duke University; B.S., Atmospheric Science, Cornell University
	4 years of experience in air quality analysis
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	B.S., Environmental Science, Brown University
	2 years of experience in waste management and climate change consulting
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	Ph.D., Atmospheric Sciences, University of Arizona; M.S., Aerospace Engineering, Boston University; B.S., Physics, Union College
	13 years of experience with climate change modeling, air quality research, and impacts analysis; 7 years of consulting experience on environmental issues; 3 years of NEPA experience
Rick Nevin, Energy Lead and Data Manager	
	M.B.A., Finance, Managerial Economics, and Strategy, Northwestern University; M.A., Economics, Boston University; B.A., Economics and Mathematics, Boston University
	29 years of experience managing and preparing environmental, energy, and economic analyses
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	B.A., Global Change and Sociology, University of Michigan
	2 years of NEPA experience
Andrew Papson, Air Quality Analyst	
	M. Eng., Transportation Engineering, University of California – Berkeley; B.S., Materials Science, Stanford University
	4 years of experience analyzing vehicle emissions and fuel efficiency
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	M.E.M., Environmental Economics and Policy, Duke University; B.S. Biology, Reed College.
	4 years environmental consulting experience; 3 years of NEPA experience

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	B.A., Economics and Environmental Policy, Williams College
	1 year of experience in climate change and sustainability issues
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	B.S., Environmental Studies, Keene State College
	2 years of NEPA experience
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	3 years of life-cycle assessment and climate change consulting experience
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	M.S., Atmospheric Science, Cornell University; B.S., Earth and Planetary Sciences, University of New Mexico
	7 years of experience in analysis of climate change impacts to water resources, terrestrial and marine ecosystems, transportation infrastructure, and human health
Emily Rowan, Climate Change Analyst	
	B.A., Science in Society, Wesleyan University
	4 years experience in climate change impacts and adaptation
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	M.R.P., Regional Planning, Cornell University; B.S. Chemistry, State University of New York at Buffalo
	25 years of experience in transportation policy, climate change, air quality, and emerging environmental issues
Peter Schultz, Senior Climate Change Advisor	
	Ph.D., Geosciences, Pennsylvania State University; M.S., Geosciences, Pennsylvania State University; B.S., Geology, Virginia Polytechnic Institute and State University
	21 years of experience in climate and global change research, management, decision support, and communication
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	A.A., General Studies, University of South Carolina
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	6 years of experience in life cycle assessment, agricultural greenhouse gas emission sources, and industrial materials recycling
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	13 years of experience analyzing climate change, greenhouse gas (GHG) emission sources, and options for reducing emissions, focusing on the energy sector
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