Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles

Final EIS

August 2016

Docket No. NHTSA-2014-0074

U.S. Department of Transportation
National Highway Traffic Safety Administration
NHTSA

Final Environmental Impact Statement
Phase 2 Fuel Efficiency Standards for
Medium- and Heavy- Duty Engines and Vehicles
Model Years 2018–2027

RESPONSIBLE AGENCY:

National Highway Traffic Safety Administration (NHTSA)

COOPERATING AGENCIES:

U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE)

TITLE:

Final Environmental Impact Statement, Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Model Years 2018-2027

OVERVIEW:

This Final Environmental Impact Statement (Final EIS) analyzes the environmental impacts of fuel efficiency standards and reasonable alternative standards for model years 2018 and beyond for medium- and heavy-duty engines and vehicles that NHTSA considered and is adopting under the Energy Policy and Conservation Act, as amended. Environmental impacts analyzed in this Final EIS include those related to fuel and energy use, air quality, and climate change. In developing the proposed Medium- and Heavy-Duty Fuel Efficiency Improvement Program, NHTSA sought to achieve the maximum feasible improvement in fuel efficiency, accounting for technological feasibility, appropriateness, and cost effectiveness, as well as relevant environmental and safety considerations. The rulemaking is consistent with President Obama's directive to improve the fuel efficiency of and reduce greenhouse gas emissions from model year 2018 and beyond medium- and heavy-duty vehicles through coordinated federal standards.

TIMING OF AGENCY ACTION:

NHTSA is issuing this Final Environmental Impact Statement concurrently with the Final Rule (Record of Decision), which states and explains NHTSA's decision and describes NHTSA's consideration of applicable environmental laws and policies. *See* 49 U.S.C. 304a (Pub. L. 114-94, 129 Stat. 1312, Sec. 1311(a)); U.S. Department of Transportation *Final Guidance on MAP-21 Section 1319 Accelerated Decisionmaking in Environmental Reviews* (http://www.dot.gov/sites/dot.gov/files/docs/MAP-21_1319_Final_Guidance.pdf).

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FINAL ENVIRONMENTAL IMPACT STATEMENT

PHASE 2 FUEL EFFICIENCY STANDARDS FOR MEDIUM- AND HEAVY-DUTY ENGINES AND VEHICLES

MODEL YEAR 2018–2027

AUGUST 2016

LEAD AGENCY:

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

COOPERATING AGENCIES:

U.S. ENVIRONMENTAL PROTECTION AGENCY AND
U.S. DEPARTMENT OF ENERGY

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Acronyms and Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
$\mu g/m^3$	micrograms of a pollutant per cubic meter of air
3D	three-dimensional
4wd	four-wheel drive
ABS	anti-lock braking system
AEO	Annual Energy Outlook
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
AMOC	Atlantic Meridional Overturning Circulation
ANL	Argonne National Laboratory
AOGCM	atmospheric-ocean general circulation model
APU	auxiliary power unit
BAC	Battery Air Conditioning
BEV	battery electric vehicle
black carbon	elemental carbon
bpd	barrels per day
Btu	British thermal unit
CAA	Clean Air Act
CAAFI	Commercial Aviation Alternative Fuels Initiative
CAFE	Corporate Average Fuel Economy (Program)
CAIT	Climate Analysis Indicators Tool
CARB	California Air Resources Board
CBO	Congressional Budget Office
CDC	Center for Disease Control and Prevention
CEQ	Council on Environmental Quality
CFC	chlorofluorocarbon
CFR	Code of Federal Regulations
CGC	Canadian Global Coupled Model
CH_4	methane
CI	combustion-ignited
CMAQ	Congestion Mitigation and Air Quality Improvement
CNG	compressed natural gas
CNP	Central North Pacific
CO	carbon monoxide
COP	Conference of the Parties
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CRI	crash rate index
CSP	Central South Pacific
dB	decibels
DGE	diesel gallon equivalents
Diesel HAD	2002 Diesel Health Assessment Document
DNA	deoxyribonucleic acid
DNL	Day-Night Average Sound Level
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy

DOT	U.S. Department of Transportation
DPF	diesel particulate filter
DPM	diesel particulate matter
DSSAT	Decision Support System for Agrotechnology Transfer
E/GDP	energy-GDP ratio
E10	blend of gasoline and ethanol containing 10 percent ethanol
E15	blend of gasoline and ethanol containing 15 percent ethanol
E85	blend of gasoline and ethanol containing 51 to 83 percent ethanol
EERE	Office of Energy Efficiency and Renewable Energy
EEZ	exclusive economic zones
EIA	U.S. Energy Information Administration
EIS	environmental impact statement
EISA	Energy and Independence Security Act of 2007
ENSO	El Niño-Southern Oscillation
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPCA	Energy Policy and Conservation Act of 1975
eTRU	electric trailer refrigeration unit
ETS	Emissions Trading System
EV	electric vehicle
FAA	Federal Aviation Administration
FFV	flexible fuel vehicle
FHWA	Federal Highway Administration
FIA	Forest Inventory and Analysis
FMCSA	Federal Motor Carrier Safety Administration
FRIA	Final Regulatory Impact Analysis
FTA	Federal Transit Administration
FY	fiscal year
g	grams
g/bhp-hr	grams per brake horsepower-hour
g/kWh	grams per kilowatt-hour
GCAM	Global Change Assessment Model
GCRP	U.S. Global Change Research Program
GCWR	gross combined weight rating
GDP	gross domestic product
GEM	Greenhouse Gas Emission Model
GHG	greenhouse gas
GHM	global hydrological model
GIS	geographic information system
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model
Gt	Gigatonnes
GVW	gross vehicle weight
GVWR	gross vehicle weight rating
GWP	Global warming potential
GYE	Greater Yellowstone Ecosystem
HD	heavy-duty [vehicle]
HD FTP	Heavy-duty Federal Test Procedure
HEI	Health Effects Institute
HEV	Hybrid Electric Vehicle

HFC	hydrofluorocarbon
HFET	Highway Fuel Economy Test
HHS	U.S. Department of Health and Human Services
HVAC	heating, ventilation, and air conditioning
IAM	Integrated Assessment Model
IARC	International Agency for Research on Cancer
IEO	International Energy Outlook
IGCC	integrated gasification combined cycle
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IPCC SREX	IPCC Special Report on Extreme Events
IPSL-CM4	Institute Pierre Simon Laplace Global Climate Model
IRIS	Integrated Risk Information System
ISO	International Organization for Standardization
IWG	Interagency Working Group on Social Cost of Carbon
JIT	Just In Time
kg	kilograms
kg/T	kilograms per metric ton
L/100km	liters per 100 kilometers
LCA	Life-Cycle Assessment
Li-ion	lithium ion
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LPJmL	Lund-Potsdam-Jena managed Land
LRR	Low-rolling resistance
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MDPV	medium-duty passenger vehicle
MIIT	Ministry of Industry and Information Technology (China)
MJ	megajoule
MLIT	Ministry of Land, Infrastructure, Transport, and Tourism (Japan)
$MMTCO_2e$	million metric tons CO_2e
MOBILE	Mobile Source Emission Factor
MOVES	Motor Vehicle Emission Simulator
mpg	miles per gallon
mph	miles per hour
MSAT	mobile source air toxic
$MTCH_4$	metric ton of CH_4
$MTCO_2$	metric ton of CO_2
MTN_2O	metric ton of N_20
MWh	Megawatt hours
MWRD	Metropolitan Water Reclamation District (Chicago)
MY	model year
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NaNiCl	nickel chloride
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCA	National Climate Assessment
NCHRP	National Cooperative Highway Research Program
NEI	National Emissions Inventory

NEPA	National Environmental Policy Act
NETL	National Energy Technology Laboratory
NF_3	nitrogen trifluoride
NG	natural gas
NGL	natural gas liquid
NH_3	ammonia
NHTSA	National Highway Traffic Safety Administration
NiCd	nickel cadmium
NiMH	nickel metal hydride
NOAA	National Oceanic and Atmospheric Administration
No Action Alternative	Alternative 1
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NPP	net primary production
NPRM	Notice of Proposed Rulemaking
NRC	National Research Council
NREL	National Renewable Energy Laboratory
OMZ	oxygen minimum zones
PbA	lead-acid
PDO	Pacific Decadal Oscillation
PEM	proton exchange membrane
PFC	Perfluorocarbon
Pg	petagrams
PgC	petagrams of carbon
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
PM2.5	particulate matter 2.5 micrometers or less in diameter
PM10	particulate matter 10 micrometers or less in diameter
POM	polycyclic organic matter
ppm	per million parts of air
Preferred Alternative	Alternative 3
PRISM	Parameter-elevation Regression on Independent Slopes Model
RCP	Representative Concentration Pathways
RF	radiative forcing
RfC	reference concentration
RFS2	Renewable Fuel Standard 2
RGGI	Regional Greenhouse Gas Initiative
RIA	Regulatory Impact Analysis
SAP	synthesis and assessment product
SC-CH_4	social cost of methane
SC-CO_2	social cost of carbon
SC-N_2O	social cost of nitrous oxide
SET	Supplemental Engine Test
SF_6	sulfur hexafluoride
SI	spark-ignited
SIP	State Implementation Plan
SO_2	sulfur dioxide
SOFC	solid oxide fuel cell
SO_x	sulfur oxides
SRES	Special Report on Emissions Scenarios

SWE	snow water equivalent
THC	thermohaline circulation
TRU	trailer refrigeration unit
TSD	Technical support document
TS&D	transportation, storage, and distribution
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UN-HABITAT	United Nations Human Settlements Programme
U.S.C.	United States Code
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Climate Research Program
UV	ultraviolet
VMT	vehicle miles traveled
VOC	volatile organic compound
VSL	value of statistical life
WBS	wide-base single
WG1	Intergovernmental Panel on Climate Change Working Group 1
W/m_2	Watts per square meter
WMO	World Meteorological Organization
WNP	Western North Pacific
WTI	West Texas Intermediate

Glossary

The glossary provides the following definitions of technical and scientific terms, as well as plain English terms used differently in the context of this EIS.

Term	Definition
Adaptation	Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, including anticipatory and reactive, private and public, and autonomous and planned.
Acrolein	A colorless irritant liquid aldehyde with a piercing, acrid smell.
Aerodynamic diameter	The diameter of the spherical particle with a density of 1,000 kg/m^3 and the same settling velocity as the irregular particle.
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 human beings.
Biofuel	Energy sources made from living things, or the waste that living things produce.
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), including dead organic matter, such as litter, soil organic matter, and oceanic detritus.
Black carbon	The most strongly light-absorbing component of particulate matter, and formed by the incomplete combustion of fossil fuels, biofuels, and biomass.
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.
Compressed natural gas	Methane stored at high pressure.
Coral bleaching	The paling in color that results if coral loses its symbiotic, energy providing, organisms.
Criteria pollutants	Carbon monoxide (CO), airborne lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and fine particulate matter (PM).
Cryosphere	The portion of Earth's surface that is frozen water, such as snow, permafrost, floating ice, and glaciers.
Dry natural gas	Also known as *consumer-grade natural gas*, dry natural gas is gas that remains after lease, field, and/or plant separation and any volumes of nonhydrocarbon gases have been removed where they occur in sufficient quantity to render the gas unmarketable.
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. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, all of Earth.
Endemic	Restricted to a region.
Eutrophication	Enrichment of a water body with plant nutrients.

Term	Definition
Evapotranspiration	The combined process of water evaporation from Earth's surface and transpiration from vegetation.
Fluorinated gases	Fluorinated greenhouse gases (GHGs) or gases include perfluorinated compounds (PFCs), hydrofluorocarbons (HFCs), sulfur hexaflouride (SF_6), and nitrogen trifluoride (NF_3).
Fuel efficiency	How much fuel a vehicle requires to perform a certain amount of work (e.g., 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.
GREET model	Model developed by Argonne National Laboratory that provides estimates of the energy and carbon contents of fuels as well as energy use in various phases of fuel supply.
Hazardous air pollutants	Substances defined as hazardous by the 1990 CAA amendments, including certain volatile organic compounds (VOCs), compounds in particulate matter, pesticides, herbicides, and radionuclides that present tangible hazards, based on scientific studies of human (and other mammal) exposure.
Hydrocarbon	An organic compound consisting entirely of hydrogen and carbon.
Hydrology	The science dealing with the occurrence, circulation, distribution, and properties of Earth's water.
Hydrosphere	The component of the climate system comprising liquid surface and subterranean water, such as oceans, seas, rivers, freshwater lakes, and underground water.
Lifetime fuel consumption	Total volume of fuel used by a vehicle over its lifetime.
Liquefied natural gas (LNG)	A natural gas (predominantly methane) that has been converted to liquid form for ease of storage or transport.
Maximum lifetime of vehicles	The age after which less than 2% of the vehicles originally produced during a model year remains in service.
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.
Mobile source air toxics (MSATs)	Hazardous air pollutants emitted from vehicles that are known or suspected to cause cancer or other serious health and environmental effects. MSATs included in this analysis are acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter, and formaldehyde.
MOVES model	The Motor Vehicle Emissions Simulator (MOVES) model used to calculate tailpipe 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.
Nonattainment area	Regions where concentrations of criteria pollutants exceed federal standards. Nonattainment areas are required to develop and implement plans to comply with the National Ambient Air Quality Standards (NAAQS) within specified time periods.
Ocean acidification	A decrease in the pH of sea water due to the uptake of anthropogenic carbon dioxide (CO_2).
Ozone	A photochemical oxidant and the major component of smog.
Particulate matter (PM)	Substances that exist as discrete particles. PM includes dust, dirt, soot, smoke, and liquid droplets directly emitted into the air.

Term	Definition
Pathways of fuel supply	Imports to the United States of refined gasoline and other transportation fuels, domestic refining of fuel using imported petroleum as a feedstock, and domestic fuel refining from crude petroleum produced within the United States.
Permafrost	Ground (soil or rock and included ice and organic material) that remains at or below zero degrees Celsius for at least two consecutive years.
Photochemical modeling	The mathematical simulation of the chemical and meteorological processes associated with the formation of ozone.
Polycyclic organic matter (POM)	A broad class of compounds that includes the polycyclic aromatic hydrocarbon compounds (PAHs). Formed primarily from combustion and present in the atmosphere in particulate form.
Primary fuel	Energy sources consumed in the initial production of energy.
Rebound effect	A situation in which improved fuel economy reduces the fuel cost of driving and leads to additional use of medium- and heavy-duty (HD) vehicles and thus increased emissions of criteria pollutants by HD vehicles.
Renewable energy	Energy coming from resources that are naturally replenished on the human timescale, e.g., sunlight, wind, rain, tides, waves, and geothermal heat.
Saltwater intrusion	Displacement of fresh surface water or groundwater by the advance of saltwater due to its greater density. This process usually occurs in coastal and estuarine areas due to reducing land-based influence (either from reduced runoff and associated groundwater recharge, or from excessive water withdrawals from aquifers) or increasing marine influence (relative sea-level rise).
Sea-ice extent	Measurement of the area of ocean where there is at least some sea ice. Usually, scientists define a threshold of minimum concentration to mark the ice edge; the most common cutoff is at 15 percent.
Shale gas	Natural gas that is trapped within shale formations, which are fine-grained sedimentary rocks that can be rich resources of petroleum and natural gas.
Social cost of carbon (SCC)	An estimate of the economic damages associated with a small increase in CO_2 emissions.
Survival rate	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.
Thermal expansion (of water)	The tendency of water to change in volume in response to a change in temperature through heat transfer.
Tipping point	A phrase used to describe situations in which the climate system reaches a point at which a disproportionately 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.
Transportation, storage, and distribution (TS&D)	The linkage of energy supplies, energy carriers, or energy by-products to intermediate and end users.
Upstream emissions	Emissions associated with crude-petroleum extraction and transportation, and with the refining, storage, and distribution of transportation fuels.
Vehicle miles traveled	Total number of miles driven.
Volatile organic compound	Emitted as gases from certain solids or liquids which are emitted by a wide variety of products.
Volpe model	Used to calculate tailpipe emissions for Classes 2b–3 vehicles.

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 Phase 2 fuel efficiency standards for commercial medium-duty and heavy-duty on-highway engines, vehicles, and trailers (hereinafter referred to collectively as "HD vehicles") for model years (MYs) 2018 and beyond (the Final Action).[1] NHTSA prepared this document 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 five alternatives to regulating HD vehicle fuel efficiency for MYs 2018 and beyond, including Alternative 3 (the Preferred Alternative/Final Action), three other action alternatives, and Alternative 1 (the No Action Alternative), and analyzes the direct, indirect, and cumulative impacts of each action alternative relative to the No Action Alternative. The action alternatives NHTSA selected for evaluation encompass a reasonable range of alternatives to evaluate the potential environmental impacts of the Final Action and alternatives under NEPA. The EIS chapters and appendices provide or reference all relevant supporting information.

Background

The Energy Policy and Conservation Act of 1975 (EPCA) mandated that NHTSA establish and implement a regulatory program for motor vehicle fuel economy. As codified in Chapter 329 of Title 49 of the U.S. Code (U.S.C.), and as amended by the Energy Independence and Security Act of 2007 (EISA), EPCA sets forth specific requirements concerning the establishment of average fuel economy standards for passenger cars and light trucks, which are motor vehicles with a gross vehicle weight rating (GVWR) less than 8,500 pounds and medium-duty passenger vehicles with a GVWR less than 10,000 pounds. This regulatory program, known as the Corporate Average Fuel Economy Program (CAFE), was established to reduce national energy consumption by increasing the fuel economy of these vehicles.

EISA provided DOT—and NHTSA, by delegation—new authority to implement, through rulemaking and regulations, "a commercial medium- and heavy-duty on-highway vehicle and work truck fuel efficiency improvement program designed to achieve the maximum feasible improvement" for motor vehicles with a GVWR of 8,500 pounds or greater, except for medium-duty passenger vehicles that are already covered under CAFE. This broad sector (HD vehicles, as described above)—ranging from large pickups to sleeper-cab tractors—represents the second-largest contributor to oil consumption and greenhouse gas (GHG) emissions from the transportation sector, after passenger cars and light trucks. EISA directs NHTSA to "adopt and implement appropriate test methods, measurement metrics, fuel economy standards, and compliance and enforcement protocols that are appropriate, cost-effective, and

[1] The Final Action establishes new standards beginning with MY 2018 for trailers and MY 2021 for all of the other heavy-duty vehicle and engine categories, with stringency increases through MY 2027 for some segments. Standards will remain at the final stringency levels until amended by a future rulemaking.

technologically feasible for commercial medium- and heavy-duty on-highway vehicles and work trucks." This new authority permits NHTSA to set "separate standards for different classes of vehicles."

Consistent with these requirements and in consultation with the U.S. Environmental Protection Agency (EPA) and Department of Energy (DOE), NHTSA established the first fuel efficiency standards for HD engines and vehicles in September 2011, as part of a comprehensive HD National Program to reduce GHG emissions and fuel consumption for HD vehicles (trailers were not included in that phase). Those fuel-efficiency standards constitute the first phase (Phase 1) of the NHTSA HD Fuel Efficiency Improvement Program. They were established to begin in MY 2016 and remain stable through MY 2018, consistent with EISA's requirements. Although EISA prevented NHTSA from enacting mandatory standards before MY 2016, NHTSA established voluntary compliance standards for MYs 2014–2015 prior to mandatory regulation in MY 2016. Throughout this EIS, NHTSA refers to the rulemaking and EIS associated with the MY 2014–2018 HD vehicle fuel efficiency standards described in this paragraph as "Phase 1" or the "Phase 1 HD National Program."

In February 2014, the president directed NHTSA and EPA to develop and issue the next phase of HD vehicle fuel efficiency and GHG standards by March 2016, as stated in the White House's 2014 report *Improving the Fuel Efficiency of American Trucks – Bolstering Energy Security, Cutting Carbon Pollution, Saving Money and Supporting Manufacturing Innovation*. Consistent with this directive, NHTSA is establishing fuel efficiency standards for HD vehicles for MYs 2018 and beyond as part of a joint rulemaking with EPA to establish what is referred to as the Phase 2 HD National Program (also referred to as "Phase 2"). As with Phase 1 and as directed by EISA, NHTSA conducted the Phase 2 rulemaking in consultation with EPA and DOE.

Pursuant to NEPA, 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 Phase 2 standards, NHTSA prepared this EIS, which analyzes, discloses, and compares the potential environmental impacts of a reasonable range of action alternatives including the No Action Alternative. This EIS also identifies a Preferred Alternative, pursuant to CEQ NEPA implementing regulations, DOT Order 5610.1C, and NHTSA regulations. The Draft EIS was issued together with the Phase 2 Notice of Proposed Rulemaking (NPRM) on June 19, 2015. NHTSA is issuing this Final EIS concurrently with the Final Rule (Record of Decision), pursuant to 49 U.S.C. 304a (Pub. L. 114-94, 129 Stat. 1312, Section 1311(a)) and U.S. Department of Transportation *Final Guidance on MAP-21 Section 1319 Accelerated Decisionmaking in Environmental Reviews*.

Purpose and Need for the Action

NEPA requires that agencies develop alternatives to a proposed action based on the action's purpose and need. The purpose of this rulemaking is to continue to promote EPCA's goals of energy independence and security, as well as to improve environmental outcomes and national security, by continuing to implement an HD Fuel Efficiency Improvement Program that is "designed to achieve the maximum feasible improvement." Congress specified that, as part of the HD Fuel Efficiency Improvement Program, NHTSA must adopt and implement appropriate test methods, measurement metrics, fuel economy standards, and compliance and enforcement protocols. These required aspects of the program must be appropriate, cost effective, and technologically feasible for HD vehicles. In developing Phase 2, NHTSA has continued to consider these EISA requirements as well as relevant environmental and safety considerations.

Although the standards established under the Phase 1 HD National Program have locked in long-lasting gains in fuel efficiency, HD vehicle fuel consumption is still projected to grow as more trucks are driven more miles. For this reason, new standards extending beyond Phase 1 are needed to further improve energy security, save money for consumers and businesses, reduce harmful air pollution, and lower costs for transporting goods. The Final Action and alternatives analyzed in this EIS have, therefore, been developed to reflect the purpose and need specified by EPCA, EISA, the Phase 1 HD National Program, and the president's 2014 directive on developing Phase 2 HD vehicle fuel efficiency and GHG standards.

Final Action and Alternatives and Analysis Methodologies

NEPA requires an agency to compare the potential environmental impacts of its proposed action and a reasonable range of alternatives. NHTSA's Action is to set HD vehicle fuel efficiency standards for MYs 2018 and beyond as part of joint rulemaking with EPA to establish what is referred to as the Phase 2 HD National Program, in accordance with EPCA, as amended by EISA. The specific alternatives NHTSA selected, described below and in Section 2.2 of this EIS, encompass a reasonable range within which to set HD vehicle fuel efficiency standards and evaluate potential environmental impacts under NEPA. Pursuant to CEQ regulations, the agency has included a No Action Alternative (Alternative 1), which assumes that NHTSA would not issue a rule regarding HD vehicle fuel efficiency standards beyond Phase 1, and assumes that NHTSA's Phase 1 HD standards and EPA's Phase 1 HD vehicle GHG standards would continue indefinitely. This alternative provides an analytical baseline against which to compare the environmental impacts of the four action alternatives.

Alternatives

The specific alternatives selected by NHTSA encompass a reasonable range of alternatives by which to evaluate the potential environmental impacts of Phase 2 of the HD Fuel Efficiency Improvement Program under NEPA. At one end of this range is the No Action Alternative, which assumes that no action would occur under the HD National Program. In addition to the No Action Alternative, NHTSA examined four action alternatives, each of which would regulate the separate segments of the HD vehicle fleet differently. Each of these action alternatives would include fuel consumption standards for engines used in Classes 2b–8 vocational vehicles and tractors (specified as gallons of fuel per horsepower-hour [gal/100 bhp-hr]); overall vehicle standards for HD pickups and vans (specified as gal/100 miles), Classes 2b–8 vocational vehicles, and Classes 7–8 tractors (specified as gallons of fuel per 1,000 ton payload miles [gal/1,000 ton-miles]); and standards for certain trailers pulled by Classes 7–8 tractors (specified as gal/1,000 ton-miles associated with "standard" reference tractors).

In the Proposed Rule and Draft EIS, the Preferred Alternative and Alternative 4 were designed to achieve similar fuel efficiency and GHG emissions levels in the long term, but with Alternative 4 being accelerated in its implementation timeline. In practice, this meant that Alternative 4 was more stringent than the Preferred Alternative in the Draft EIS. In response to comments received on the Proposed Rule and

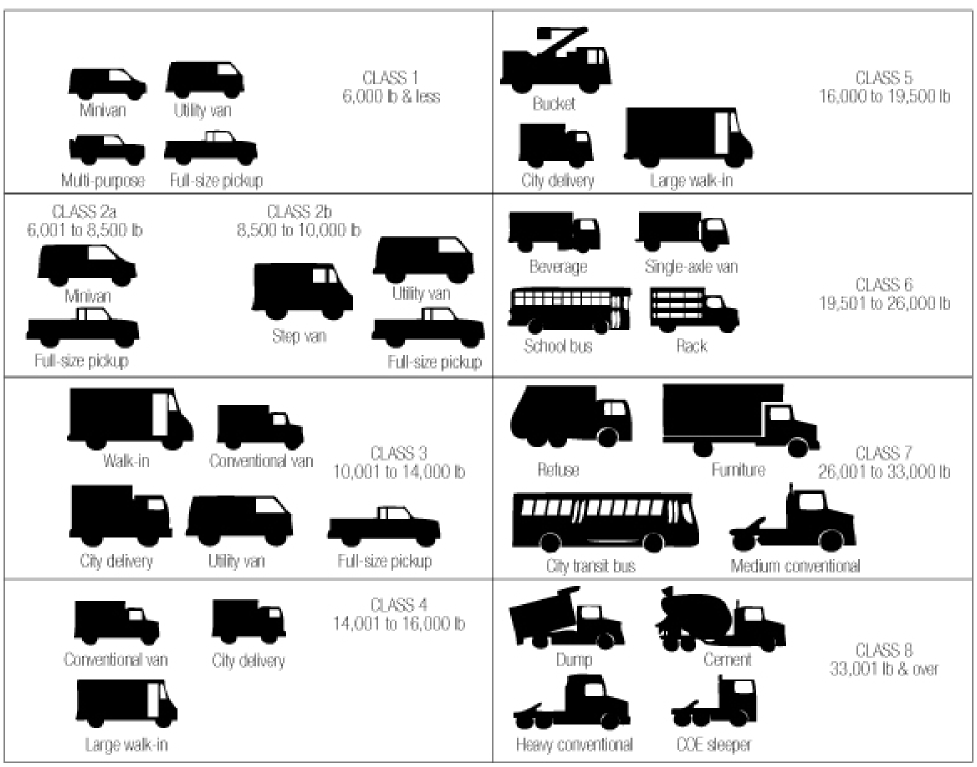
Draft EIS, the agencies revised the Preferred Alternative. As a result, the Final EIS standards for the Preferred Alternative are more stringent than the Draft EIS proposed standards for the Preferred Alternative. Standards for Alternative 4 in this Final EIS are the same as the Alternative 4 standards in the Draft EIS in order to provide a benchmark for comparison of the revised Preferred Alternative. Now, the Preferred Alternative is more stringent than Alternative 4 in this Final EIS for some vehicle categories. Under Alternative 2, standards are less stringent than the Preferred Alternative or Alternative 4. Alternative 5 represents more stringent standards compared to Alternatives 3 and 4. Alternatives 2 through 5 would regulate the same vehicle categories, with Alternative 2 being the least stringent alternative and Alternative 5 being the most stringent.

Table S-1 and Figure S-1 show the vehicle categories that are the subject of the Final Rule. Section I of the Final Rule and Section 2.2 provide more details about these vehicle categories and the specific standards for the Preferred Alternative and other action alternatives.

Table S-1. HD Vehicle Categories by Gross Vehicle Class Weight Rating (pounds)

<table>
<tr><th>Class 2b</th><th>Class 3</th><th>Class 4</th><th>Class 5</th><th>Class 6</th><th>Class 7</th><th>Class 8</th></tr>
<tr><td>8,501–10,000</td><td>10,001–14,000</td><td>14,001–16,000</td><td>16,001–19,500</td><td>19,501–26,000</td><td>26,001–33,000</td><td>>33,000</td></tr>
<tr><td colspan="2">HD Pickups and Vans (work trucks)</td><td colspan="5"></td></tr>
<tr><td colspan="7">Vocational Vehicles (e.g., van trucks, utility “bucket” trucks, tank trucks, refuse trucks, buses, fire trucks, flat-bed trucks, and dump trucks)</td></tr>
<tr><td colspan="5"></td><td colspan="2">Tractors (for combination tractor-trailers)</td></tr>
</table>

Figure S-1. HD Vehicle Categories



Potential Environmental Consequences

This section describes how the Final Action and alternatives could affect energy use, air quality, and climate (including non-climate impacts of carbon dioxide [CO_2]), as reported in Chapters 3, 4, and 5 of the EIS, respectively. The EIS also provides a life-cycle impact assessment of vehicle energy, materials, and technologies, as reported in Chapter 6 of the EIS. This EIS also qualitatively describes potential additional impacts on hazardous materials and regulated wastes, historic and cultural resources, safety impacts on human health, noise, and environmental justice, as reported in Chapter 7 of the EIS.

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

To derive the impacts of the action alternatives, NHTSA compares the action alternatives to the No Action Alternative. The action alternatives in the direct and indirect impacts analysis and the cumulative impacts analysis are the same, but the No Action Alternative under each analysis reflects different assumptions to distinguish between direct and indirect impacts versus cumulative impacts.

- The analysis of direct and indirect impacts compares action alternatives with a No Action Alternative that generally reflects a small forecast improvement in the average fuel efficiency of new HD vehicles after 2018 due to market-based incentives for improving fuel efficiency. In this way, the analysis of direct and indirect impacts isolates the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the rule, and not attributable to reasonably foreseeable future actions by manufacturers after 2018 to improve new HD vehicle fuel efficiency even in the absence of new regulatory requirements.
- The analysis of cumulative impacts compares action alternatives with a No Action Alternative that generally reflects no forecast improvement in the average fuel efficiency of new HD vehicles after 2018. As a result, the difference between the environmental impacts of the action alternatives and the cumulative impacts baseline reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 (i.e., reasonably foreseeable future changes in HD vehicle fuel efficiency) and the direct and indirect impacts of the Phase 2 standards associated with each action alternative. Therefore, this analysis reflects the cumulative impacts of reasonably foreseeable improvements in fuel efficiency after 2018 due to market-based incentives in addition to the direct and indirect impacts of the Phase 2 HD standards associated with each action alternative.

Energy

NHTSA's Phase 2 standards regulate HD vehicle fuel efficiency and, therefore, affect U.S. transportation 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 transportation fuel consumption will account for most U.S. net energy imports through 2040 (as explained in Chapter 3 of the EIS), the United States has the potential to achieve large reductions in imported oil use and, consequently, in net energy imports during this time by improving the fuel efficiency of HD vehicles. Reducing dependence on energy imports is a key component of President

Obama's May 29, 2014, *All-of-the-Above Energy Strategy*, which states that the development of HD Phase 2 standards "will lead to large savings in fuel, lower carbon dioxide (CO_2) emissions, and health benefits from reduced particulate matter and ozone."

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. From 2000 to 2011, the United States recorded substantial GDP growth with almost no increase in energy consumption because of reductions in energy intensity. The Annual Energy Outlook (AEO) 2015 forecasts ongoing declines in U.S. energy intensity, with average 2013–2040 GDP growth of 2.4 percent per year resulting in average annual energy consumption growth of just 0.3 percent.

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.

Petroleum is by far the largest source of energy used in the transportation sector. In 2012, petroleum supplied 92 percent of transportation energy demand, and in 2040, petroleum is expected to supply 87 percent of transportation energy demand. Consequently, transportation accounts for the largest share of total U.S. petroleum consumption. In 2012, the transportation sector accounted for 79 percent of total U.S. petroleum consumption. In 2040, transportation is expected to account for 75 percent of total U.S. petroleum consumption.

With petroleum expected to account for all U.S. net energy imports in 2040 and transportation expected to account for 75 percent of total petroleum consumption, U.S. net energy imports in 2040 are expected to result primarily from fuel consumption by light-duty and HD vehicles. The United States is poised to reverse the trend of the last 4 decades and achieve large reductions in net energy imports through 2040 due to continuing increases in U.S. energy efficiency and recent developments in U.S. energy production. Stronger fuel efficiency standards for HD vehicles have the potential to increase U.S. energy efficiency in the transportation sector further and reduce U.S. dependence on petroleum.

In the future, the transportation sector will continue to be the largest component of U.S. petroleum consumption 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 HD vehicles 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 action 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 2019–2050 (2050 is the year by which nearly the entire U.S. HD vehicle fleet will most likely be composed of vehicles that are subject to the Phase 2 standards).

Direct and Indirect Impacts

As the alternatives increase in stringency, total fuel consumption decreases. Table S-2 shows total 2019–2050 fuel consumption for each alternative and the direct and indirect fuel savings for each action alternative compared with the No Action Alternative through 2050. This table reports total 2019–2050 fuel consumption in diesel gallon equivalents (DGE) for diesel, gasoline, natural gas (NG), and E85 fuel for HD pickups and vans (Classes 2b–3), vocational vehicles (Classes 2b–8), and tractor-trailers (Classes 7–8) for each alternative. Gasoline accounts for approximately 56 percent of HD pickup and van fuel use, 21 percent of vocational vehicle fuel use, and just 0.0001 percent of tractor-trailer fuel use. E85 accounts for less than 0.4 percent of HD pickup and van fuel use, and NG accounts for less than 1 percent of vocational vehicle and HD pickup and van fuel use. Diesel accounts for approximately 43 percent of HD pickup and van fuel use, 78 percent of vocational vehicle fuel use, and 100 percent of tractor trailer fuel use.

Table S-2. Direct and Indirect HD Vehicle Fuel Consumption and Fuel Savings Impacts by Alternative, 2019–2050

	Billion Diesel Gallon Equivalents (DGE)				
	Alt. 1 – No Action	**Alt. 2**	**Alt. 3 – Preferred**	**Alt. 4**	**Alt. 5**
Fuel Consumption					
HD Pickups and Vans	296.5	282.7	272.1	271.2	267.5
Vocational Vehicles	364.1	344.8	324.3	330.3	316.5
Tractor Trucks and Trailers	1,182.9	1,130.1	1,015.9	1,041.7	972.4
All HD Vehicles	**1,843.6**	**1,757.6**	**1,612.4**	**1,643.3**	**1,556.4**
Fuel Savings Compared to Alt. 1 – No Action					
HD Pickups and Vans	--	13.8	24.4	25.3	29.0
Vocational Vehicles	--	19.3	39.8	33.8	47.6
Tractor Trucks and Trailers	--	52.8	167.0	141.2	210.6
All HD Vehicles	**--**	**85.9**	**231.2**	**200.3**	**287.1**

Total fuel consumption from 2019 through 2050 across all HD vehicle classes under the No Action Alternative is projected to amount to 1,843.6 billion DGE. Total projected 2019–2050 fuel consumption across the action alternatives ranges from 1,757.6 billion DGE under Alternative 2 to 1,556.4 billion DGE under Alternative 5. Less fuel would be consumed under each of the action alternatives than under the No Action Alternative, with total 2019–2050 direct and indirect fuel savings ranging from 85.9 billion DGE under Alternative 2 to 287.1 billion DGE under Alternative 5. Under the Preferred Alternative, total projected fuel consumption from 2019–2050 would be 1,612.4 billion DGE, and direct and indirect fuel savings compared with the No Action Alternative would be 231.2 billion DGE.

Cumulative Impacts

As with direct and indirect impacts, fuel consumption under each action alternative would decrease with increasing stringency under the cumulative impacts analysis, which incorporates other past, present, and reasonably foreseeable future actions that would lead to improvements in HD vehicle fuel efficiency. Table S-3 shows total 2019–2050 fuel consumption for each alternative and the cumulative fuel savings for each action alternative compared with the No Action Alternative through 2050. Total 2019–2050 fuel consumption for each action alternative in this table is the same as shown for the corresponding action alternative in Table S-2. The No Action Alternative's fuel consumption is higher in Table S-3 than in Table S-2 because the No Action Alternative's fuel consumption in Table S-3 generally does not reflect forecast improvements in the average fuel efficiency of new HD vehicles MYs 2018 and beyond due to market forces. The cumulative impact fuel savings resulting from each action alternative are higher in Table S-3 than the direct and indirect impact fuel savings reported in Table S-2 because the fuel savings in Table S-3 reflect the cumulative impact of market-based incentives for improving fuel efficiency after 2018, plus the direct and indirect impacts of the Phase 2 HD standards associated with each action alternative.

Table S-3. Cumulative HD Vehicle Fuel Consumption and Fuel Savings Impacts by Alternative, 2019–2050

	Billion Diesel Gallon Equivalents (DGE)				
	Alt. 1 – No Action	**Alt. 2**	**Alt. 3 – Preferred**	**Alt. 4**	**Alt. 5**
Fuel Consumption					
HD Pickups and Vans	298.6	282.7	272.1	271.2	267.5
Vocational Vehicles	364.1	344.8	324.3	330.3	316.5
Tractor Trucks and Trailers	1,203.2	1,130.1	1,015.9	1,041.7	972.4
All HD Vehicles	**1,865.9**	**1,757.6**	**1,612.4**	**1,643.3**	**1,556.4**
Fuel Savings Compared to Alt. 1 – No Action					
HD Pickups and Vans	--	15.9	26.5	27.4	31.1
Vocational Vehicles	--	19.3	39.8	33.8	47.6
Tractor Trucks and Trailers	--	73.0	187.3	161.4	230.8
All HD Trucks	**--**	**108.3**	**253.5**	**222.6**	**309.4**

Total fuel consumption from 2019 through 2050 across all HD vehicle classes under the No Action Alternative in Table S-3 is projected to amount to 1,865.9 billion DGE. Total 2019–2050 projected fuel consumption across alternatives ranges from 1,757.6 billion DGE under Alternative 2 to 1,556.4 billion DGE under Alternative 5. Less fuel would be consumed under each of the action alternatives than under the No Action Alternative, with total 2019–2050 cumulative fuel savings ranging from 108.3 billion DGE under Alternative 2 to 309.4 billion DGE under Alternative 5. Under the Preferred Alternative, total projected fuel consumption from 2019–2050 would be 1,612.4 billion DGE, and cumulative fuel savings compared with the No Action Alternative would be 253.5 billion DGE.

Air Quality

Air pollution and air quality can affect public health, public welfare, and the environment. The Final Action and alternatives 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 on human health, and the monetized health benefits of emissions reductions. Although air pollutant emissions generally decline under the action alternatives compared with the No Action Alternative, the magnitudes of the declines are not consistent across all pollutants (and some air pollutant emissions might increase). This inconsistency reflects the complex interactions between tailpipe emissions rates of the various vehicle types, the technologies NHTSA assumes manufacturers will incorporate to comply with the standards, upstream emissions 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 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 (PM10) and 2.5 microns (PM2.5, or fine particles). Ozone is not emitted directly from vehicles but is formed from emissions of ozone precursor pollutants such as nitrogen oxides (NO_X) and volatile organic compounds (VOCs).

In addition to criteria pollutants, motor vehicles emit some substances defined by the 1990 Clean Air Act 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 PM2.5 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. Nevertheless, the U.S. transportation sector remains a major source of emissions of certain criteria pollutants or their chemical precursors. On-road mobile sources (i.e., highway vehicles, including vehicles covered by the Final Rule) are responsible for 24,796,000 tons per year of CO (34 percent of total U.S. emissions), 185,000 tons per year (3 percent) of PM2.5 emissions, and 268,000 tons per year (1 percent) of PM10 emissions. HD vehicles contribute 6 percent of U.S. highway emissions of CO, 66 percent of highway emissions of PM2.5, and 55 percent of highway emissions of PM10. Almost all of the PM in motor vehicle exhaust is PM2.5; therefore, this analysis focuses on PM2.5 rather than PM10. On-road mobile sources also contribute 2,161,000 tons per year (12 percent of total nationwide emissions) of VOCs and 5,010,000 tons per year (38 percent) of NO_X emissions, which are chemical precursors of ozone. HD vehicles contribute 8 percent of U.S. highway emissions of VOCs and 50 percent of NO_X. In addition, NO_X is a PM2.5 precursor, and VOCs can be PM2.5 precursors. SO_2 and other oxides of sulfur (SO_X) are important because they contribute to the formation of PM2.5 in the atmosphere; however, on-road mobile sources account for less than 0.56 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 and is therefore not assessed in this analysis.

Methodology

To analyze air quality and human health impacts, NHTSA calculated the emissions of criteria pollutants and MSATs from HD vehicles 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 results, including impacts on human health, are based on a number of assumptions about the type and rate of emissions from the combustion of fossil fuels. In addition to tailpipe emissions, this analysis accounts for upstream emissions from the production and distribution of fuels. To estimate Classes 2b–3 upstream emissions changes resulting from the decreased downstream fuel consumption, the analysis uses the Volpe HD model, which incorporates emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET) model (2013 version developed by the U.S. Department of Energy Argonne National Laboratory). The Volpe HD model uses the decreased volumes of the fuels along with the emissions factors from GREET for the various fuel production and transport processes to estimate the net changes in upstream emissions as a result of fuel consumption changes. To estimate Classes 4–8 upstream emissions, the analysis uses a spreadsheet model developed by EPA that uses an identical methodology based on GREET emissions factors.

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 HD vehicle miles traveled would be accounted for by vehicles that meet the Phase 2 standards. The EIS provides findings for air quality effects for 2018, 2025, 2040, and 2050. In general, emissions of criteria air pollutants decrease with increased stringency across alternatives, with few exceptions. The changes in emissions reflect the complex interactions among the tailpipe emissions rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the Phase 2 standards, upstream emissions rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and increases in VMT. To estimate the reduced incidence of PM2.5-related adverse health effects and the associated monetized health benefits from the emissions reductions, NHTSA multiplied direct PM2.5 and PM2.5 precursor (NO_X, SO_2, and VOCs) emissions reductions by EPA-provided pollutant-specific benefit-per-ton estimates. Reductions in adverse health outcomes include reduced incidences of premature mortality, acute bronchitis, respiratory emergency room visits, and work-loss days.

Direct and Indirect Impacts

<u>Criteria Pollutants</u>

- Emissions of criteria pollutants are highest under the No Action Alternative; they decline as fuel consumption decreases from the least stringent action alternative (Alternative 2) to the most stringent alternative (Alternative 5), with the exception of Alternative 4 for some pollutants and years, and CO emissions which increase slightly under all action alternatives in 2018 (Figure S-2). Many of the emissions changes are relatively small, especially for CO and PM2.5, which were reduced by less than 13 percent in 2040 under all alternatives.
- Emissions reductions were greatest under Alternative 5 for all criteria pollutants (except CO in 2018). By 2050 these reductions ranged from 7 percent for CO to 22 percent for SO_2.
- Under the Preferred Alternative, emissions of all criteria pollutants in 2040 are reduced compared to emissions under the No Action Alternative. By 2050 these reductions ranged from 4 percent for CO to 19 percent for SO_2.

<u>Hazardous Air Pollutants</u>

- Emissions of MSATs are highest under the No Action Alternative; they decline as fuel consumption decreases from the least stringent action alternative (Alternative 2) to the most stringent alternative (Alternative 5), with the exception of Alternatives 2, 4, and 5 for acrolein and 1,3-butadiene (Figure S-3). The emissions changes are relatively small, less than 8 percent for all MSATs under all alternatives and years.
- Emissions changes were greatest under Alternatives 4 and 5 for all MSATs, with the exception that changes in acetaldehyde and acrolein emissions were greatest under the Preferred Alternative in some years. By 2050 these changes ranged from a reduction of 8 percent for benzene (under Alternative 5) to an increase of 5 percent for 1,3-butadiene (under Alternative 4).

Figure S-2. Nationwide Criteria Pollutant Emissions (tons/year) from U.S. HD Vehicles for 2040 by Alternative, Direct and Indirect Impacts

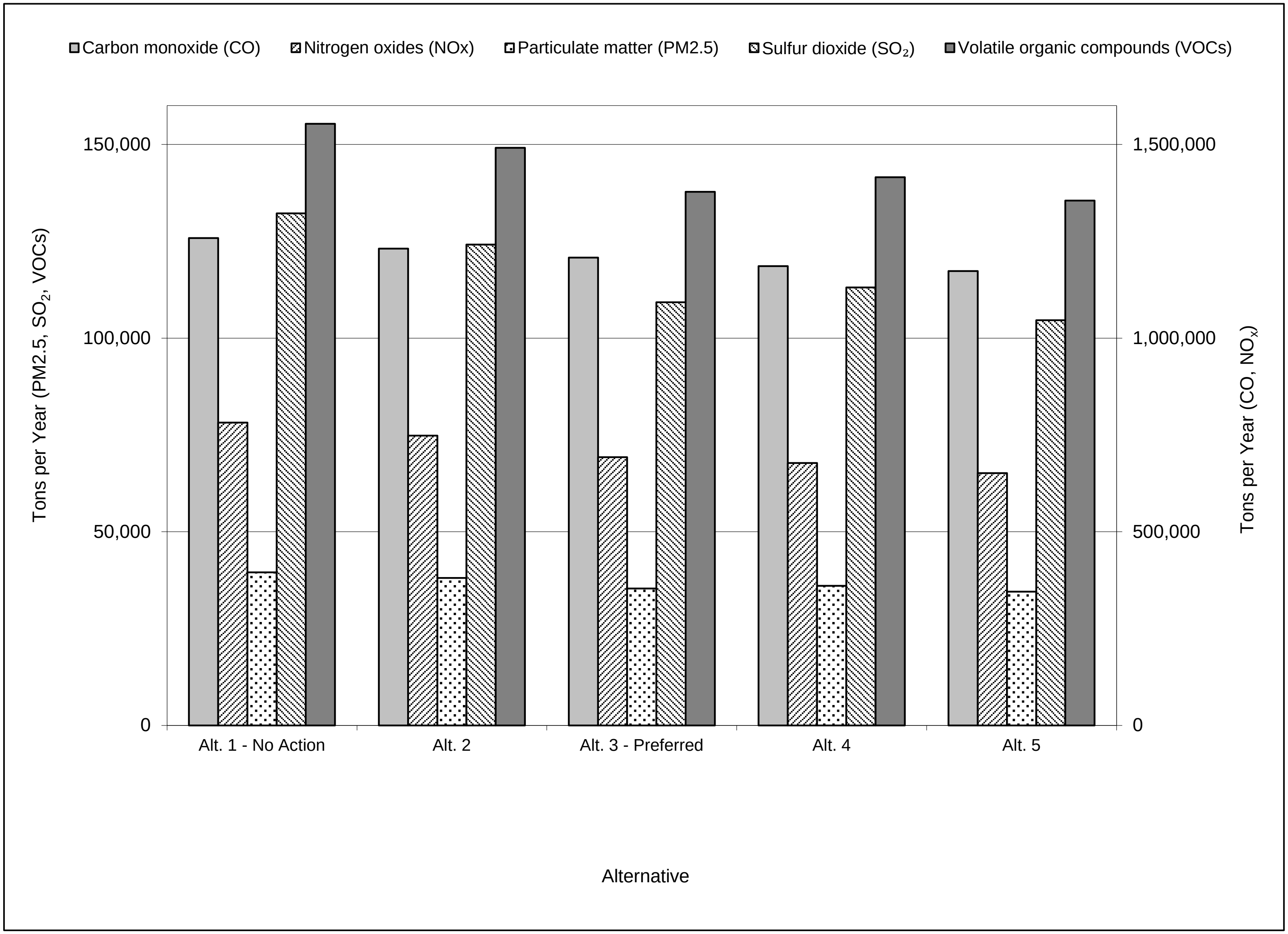
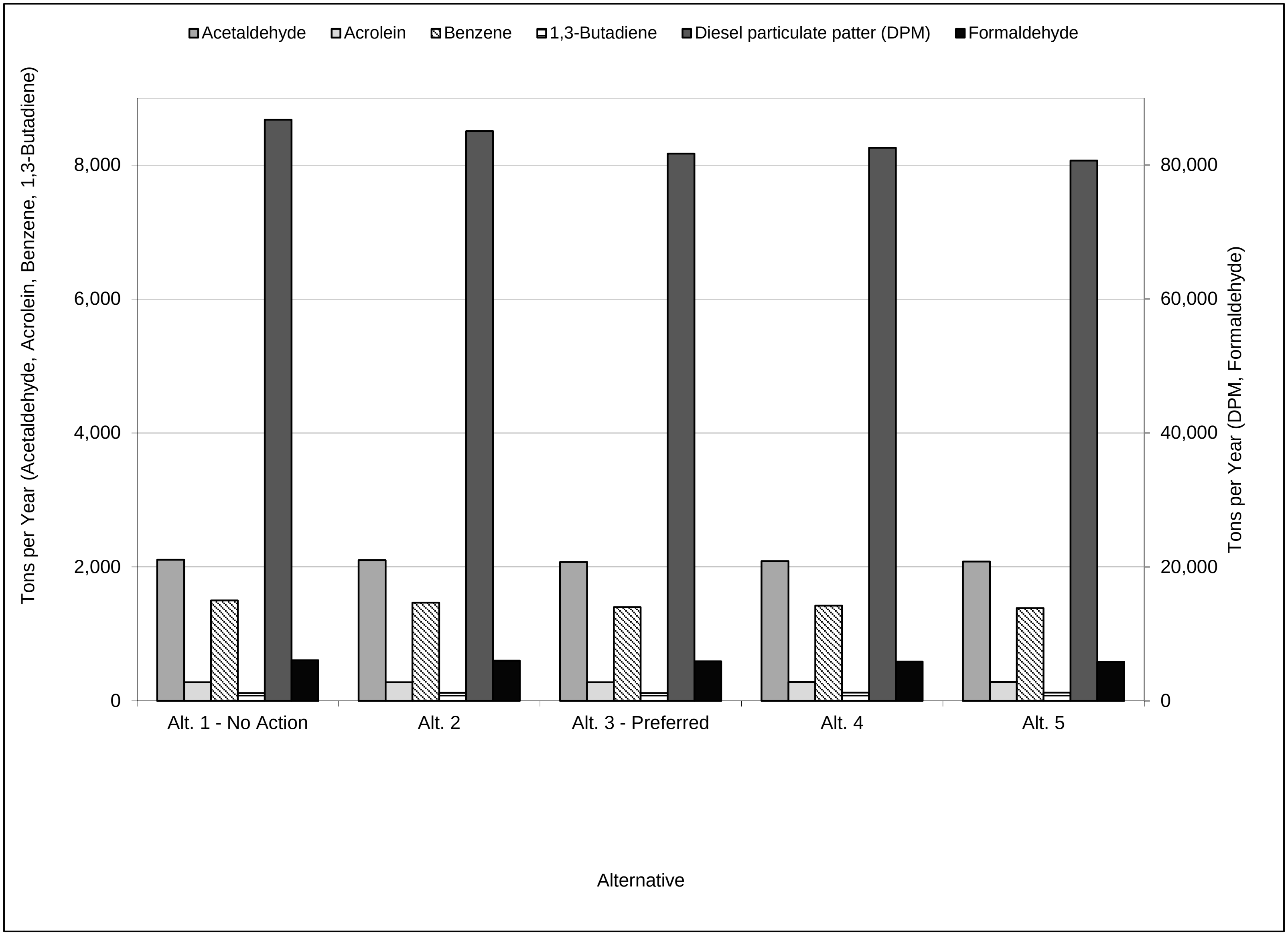


Figure S-3. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. HD Vehicles for 2040 by Alternative, Direct and Indirect Impacts



- Under the Preferred Alternative, emissions of all MSATs in 2040 are reduced compared to emissions under the No Action Alternative. Under the Preferred Alternative by 2050, emissions of 1,3-butadiene were reduced by less than 1 percent, emissions of acrolein by 1 percent, emissions of acetaldehyde by 2 percent, emissions of formaldehyde by 3 percent, emissions of DPM by 6 percent, and emissions of benzene by 7 percent.

Health and Monetized Health Benefits

- All action alternatives would generally result in reduced adverse health effects (mortality, acute bronchitis, respiratory emergency room visits, and work-loss days) nationwide compared with the No Action Alternative, with increasing reductions from the least stringent (Alternative 2) to the most stringent (Alternative 5) alternatives, with the exception of Alternative 4 in some analysis years.
- Because monetized health benefits increase with reductions in adverse health effects, monetized benefits increase across alternatives along with increasing HD vehicle fuel efficiency standards, again with the exception of Alternative 4 in some analysis years. When estimating quantified and monetized health impacts, EPA relies on results from two PM2.5-related premature mortality studies it considers equivalent: Krewski et al. (2009) and Lepeule et al. (2012). EPA recommends that monetized benefits be shown by using incidence estimates derived from each of these studies and valued using 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. Using these four calculations, estimated monetized health benefits in 2040 range from $1.8 billion to $15.5 billion under all action alternatives.
- Estimated monetized health benefits in 2040 range from $1.8 to $4.4 billion under Alternative 2, $5.0 to $12.4 billion under the Preferred Alternative, $4.5 to $11.2 billion under Alternative 4, and $6.2 to $15.5 billion under Alternative 5.

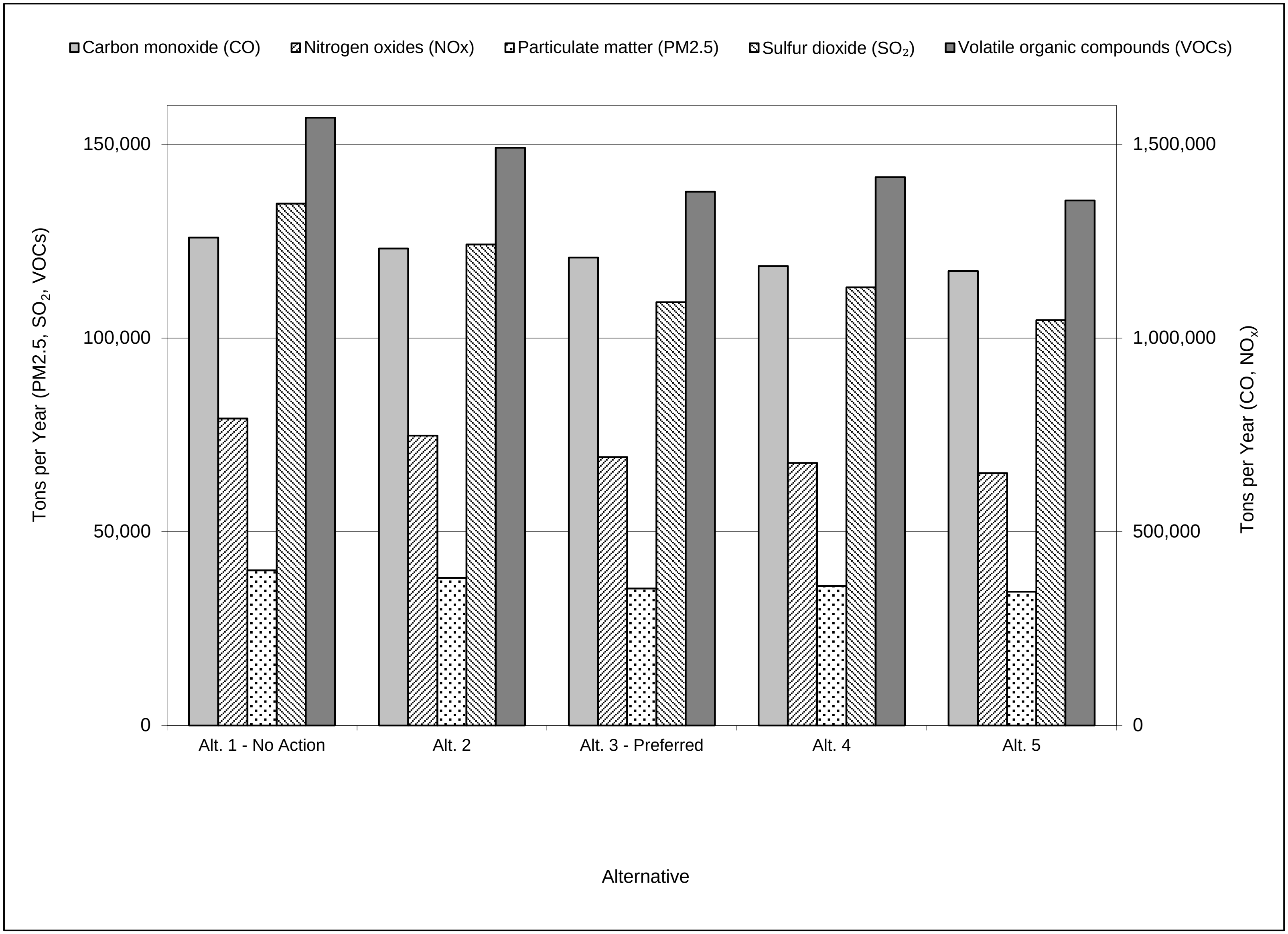
See Section 4.2.1 of this EIS for data on the direct effects of criteria and hazardous air pollutant emissions and the monetized health benefits for the alternatives.

Cumulative Impacts

Criteria Pollutants

- Cumulative emissions of criteria pollutants are highest under the No Action Alternative; they decline as fuel consumption decreases across the action alternatives, with the exception of Alternative 4 for some pollutants and years, and CO emissions which increase slightly under all action alternatives in 2018. Many of the emissions changes are relatively small, especially for CO and PM2.5, which were reduced by 14 percent or less in 2040 under all alternatives (Figure S-4).
- Emissions reductions were greatest under Alternative 5 for all criteria pollutants (except CO in 2018). By 2050 these reductions ranged from 7 percent for CO to 24 percent for SO_2.
- Under the Preferred Alternative, emissions of all criteria pollutants in 2040 are reduced compared to emissions under the No Action Alternative. By 2050 these reductions ranged from 4 percent for CO to 17 percent for SO_2**.**

Figure S-4. Nationwide Criteria Pollutant Emissions (tons/year) from U.S. HD Vehicles for 2040 by Alternative, Cumulative Impacts



Hazardous Air Pollutants

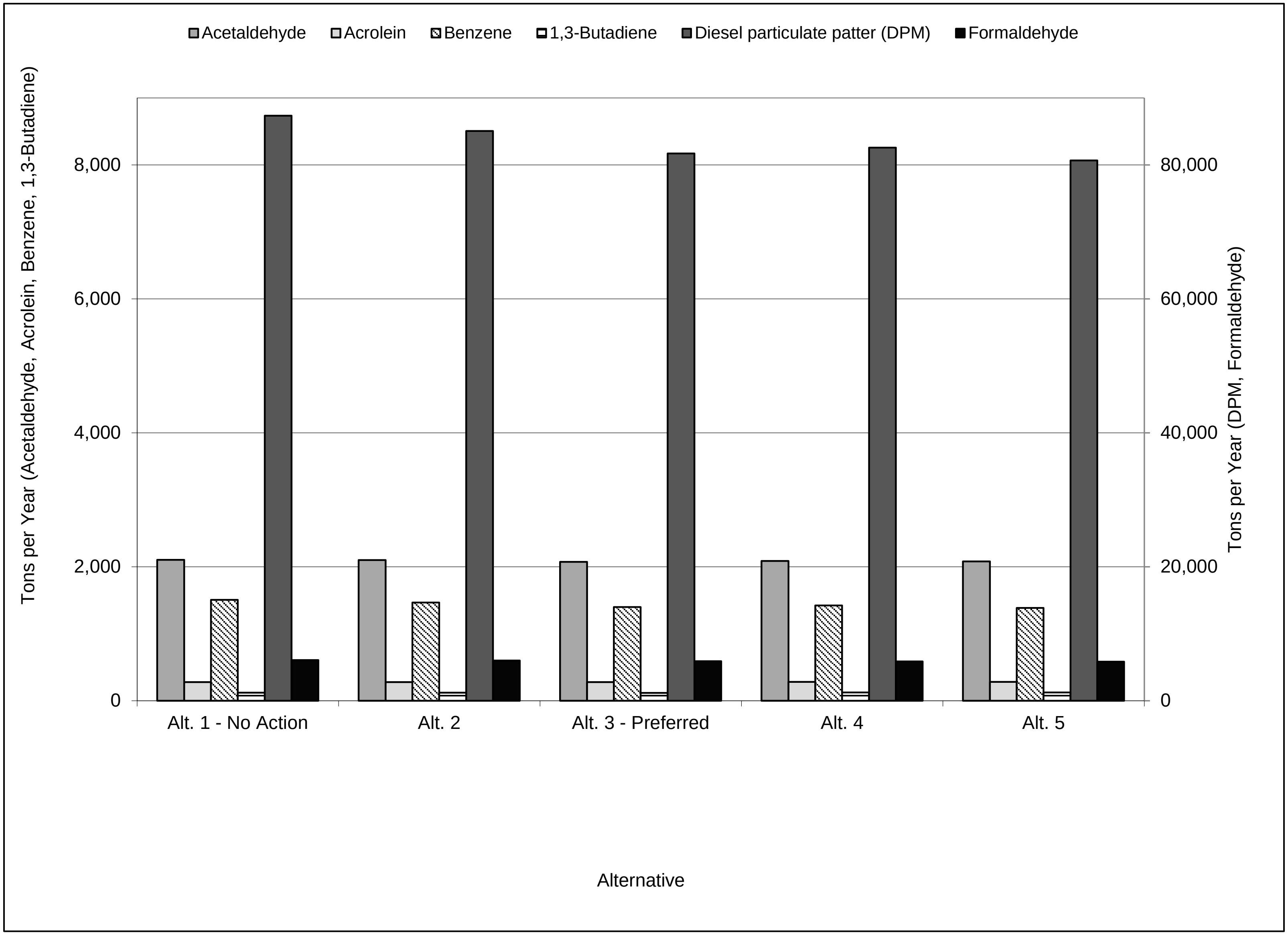
- Emissions of MSATs are highest under the No Action Alternative; they generally decline as fuel consumption decreases from the least stringent action alternative (Alternative 2) to the most stringent alternative (Alternative 5), with the exception of Alternatives 2, 4, and 5 for acrolein and 1,3-butadiene (Figure S-5). The emissions changes are relatively small, less than 9 percent for all MSATs under all alternatives and years.
- Emissions changes were greatest under Alternatives 4 and 5 for all MSATs, with the exception that changes in acetaldehyde and acrolein emissions were greatest under the Preferred Alternative in some years. By 2050 these reductions ranged from a reduction of 9 percent for benzene (under Alternative 5) to an increase of 4 percent for 1,3-butadiene (under Alternative 4).
- Under the Preferred Alternative, emissions of all MSATs in 2040 are the same or reduced compared to emissions under the No Action Alternative. By 2050, emissions of 1,3-butadiene were reduced by less than 1 percent, emissions of acrolein by 1 percent, emissions of acetaldehyde by 1 percent, emissions of formaldehyde by 3 percent, emissions of DPM by 7 percent, and emissions of benzene by 8 percent.

Health and Monetized Health Benefits

- All action alternatives would generally result in reduced adverse health effects (mortality, acute bronchitis, emergency room visits for asthma, and work-loss days) nationwide compared with the No Action Alternative, with the same or increasing reductions from the least stringent (Alternative 2) to the most stringent (Alternative 5) alternatives, with the exception of Alternative 4 in some analysis years.
- Estimated monetized health benefits in 2040 range from $2.3 to $17.0 billion for all alternatives.
- Estimated monetized health benefits in 2040 range from $2.3 to $5.8 billion under Alternative 2, $5.6 to $13.9 billion under the Preferred Alternative, $5.1 to $12.6 billion under Alternative 4, and $6.8 to $17.0 billion under Alternative 5.

See Section 4.2.2 of this EIS for cumulative impacts data on criteria and hazardous air pollutant emissions and the monetized health benefits for the alternatives.

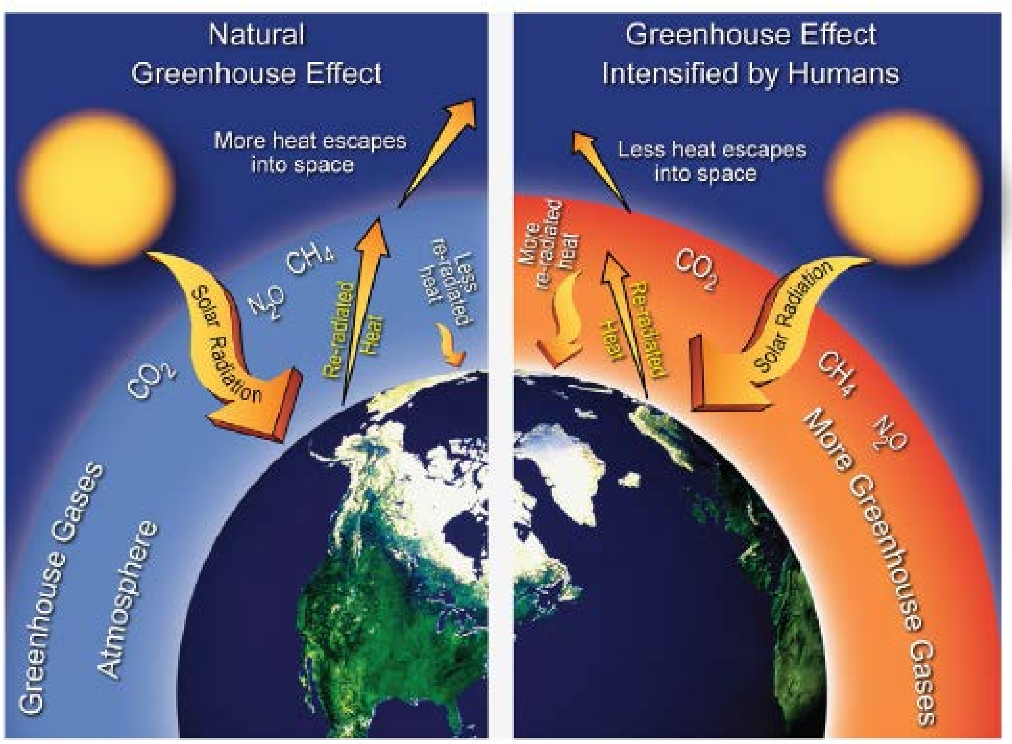
Figure S-5. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. HD Vehicles for 2040 by Alternative, Cumulative Impacts



Climate

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 4 to 12 miles above the surface) by absorbing heat energy emitted by Earth's surface and lower atmosphere, and reradiating much of it back to Earth's surface, thereby causing warming. This process, known as the *greenhouse effect*, is responsible for maintaining surface temperatures that are warm enough to sustain life. Most GHGs, including CO_2, methane (CH_4), nitrous oxide (N_2O), water vapor, and ozone, occur naturally. Human activities, particularly fossil-fuel combustion, lead to the presence of increased concentrations of GHGs in the atmosphere, thereby intensifying the warming associated with the Earth's greenhouse effect (Figure S-6).

Figure S-6. Human Influence on the Greenhouse Effect



Source: GCRP (U.S. Global Change Research Program) 2014. Global Climate Change Impacts in the United States. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. Washington, DC.

Since the industrial revolution, when fossil fuels began to be burned in increasing quantities, concentrations of GHGs in the atmosphere have increased. Atmospheric concentrations of CO_2 have increased by more than 40 percent since pre-industrial times, while the concentration of CH_4 is now 150 percent above pre-industrial levels. This buildup of GHGs in the atmosphere is changing the 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 approximately 0.8 degree Celsius (°C) (1.4 degrees Fahrenheit [°F]), and sea levels have risen 19 centimeters (7.5 inches), with a rate of increase of approximately 3.2 millimeters (0.13 inch) per year from 1993 to 2010. These observed changes in the global climate are largely a result of GHG emissions from human activities. The United Nations Environment Programme and the World Meteorological Organization established Intergovernmental Panel on Climate Change (IPCC) has concluded that "[H]uman influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea-level rise, and in changes in some climate extremes…It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century."

Throughout this EIS, NHTSA has relied extensively on findings of the IPCC, U.S. Climate Change Science Program (CCSP), National Research Council (NRC), Arctic Council, U.S. Global Change Research Program (GCRP), and EPA. This 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, and severe weather events, which in turn could affect human health and safety, infrastructure, food and water supplies, and natural ecosystems. For example:

- Impacts on freshwater resources could include changes in water demand such as significant increases in irrigation needs, water shortages, general variability in water supply, and increasing flood risk in response to flooding, drought, changes in snowpack and the timing of snow melt, changes in weather patterns, and saltwater intrusions from sea-level rise.
- Impacts on terrestrial and freshwater ecosystems could include shifts in the range and seasonal migration patterns of species, relative timing of species' life-cycle events, potential extinction of sensitive species that are unable to adapt to changing conditions, increases in the occurrence of forest fires and pest infestations, and changes in habitat productivity due to increased atmospheric concentrations of CO_2.
- Impacts on ocean systems, coastal, and low-lying areas could include the loss of coastal areas due to submersion and/or erosion, reduction in coral reefs and other key habitats thereby affecting the distribution, abundance, and productivity of many marine species, increased vulnerability of the built environment and associated economies to severe weather and storm surges, and increased salinization of estuaries and freshwater aquifers.
- Impacts on food, fiber, and forestry could include increasing tree mortality, forest ecosystem vulnerability, productivity losses in crops and livestock, and changes in the nutritional quality of pastures and grazelands in response to fire, insect infestations, increases in weeds, drought, disease outbreaks, and/or extreme weather events. Many marine fish species could migrate to deeper and/or colder water in response to rising ocean temperatures. Impacts on food, including yields, food processing, storage, and transportation, could affect food prices and food security globally.
- Impacts on rural and urban areas could include affecting water and energy supplies, wastewater and stormwater systems, transportation, telecommunications, provision of social services, agricultural incomes, and air quality. The impacts could be greater for vulnerable populations such as lower-income populations, the elderly, those with existing health conditions, and young children.

- Impacts on human health could include increased mortality and morbidity due to excessive heat, increases in respiratory conditions due to poor air quality and aeroallergens, increases in water and food-borne diseases, changes in the seasonal patterns of vector-borne diseases, and increases in malnutrition. The most disadvantaged groups such as children, elderly, sick, and low-income populations are especially vulnerable.
- Impacts on human security could include increased threats in response to adversely affected livelihoods, compromised cultures, increased and/or restricted migration, increased risk of armed conflicts, reduction in providing adequate essential services such as water and energy, and increased geopolitical rivalry.

Climate change has been projected to have a direct impact on stratospheric ozone recovery, although there are large elements of uncertainty within these projections.

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 adversely affects corals and other marine life.

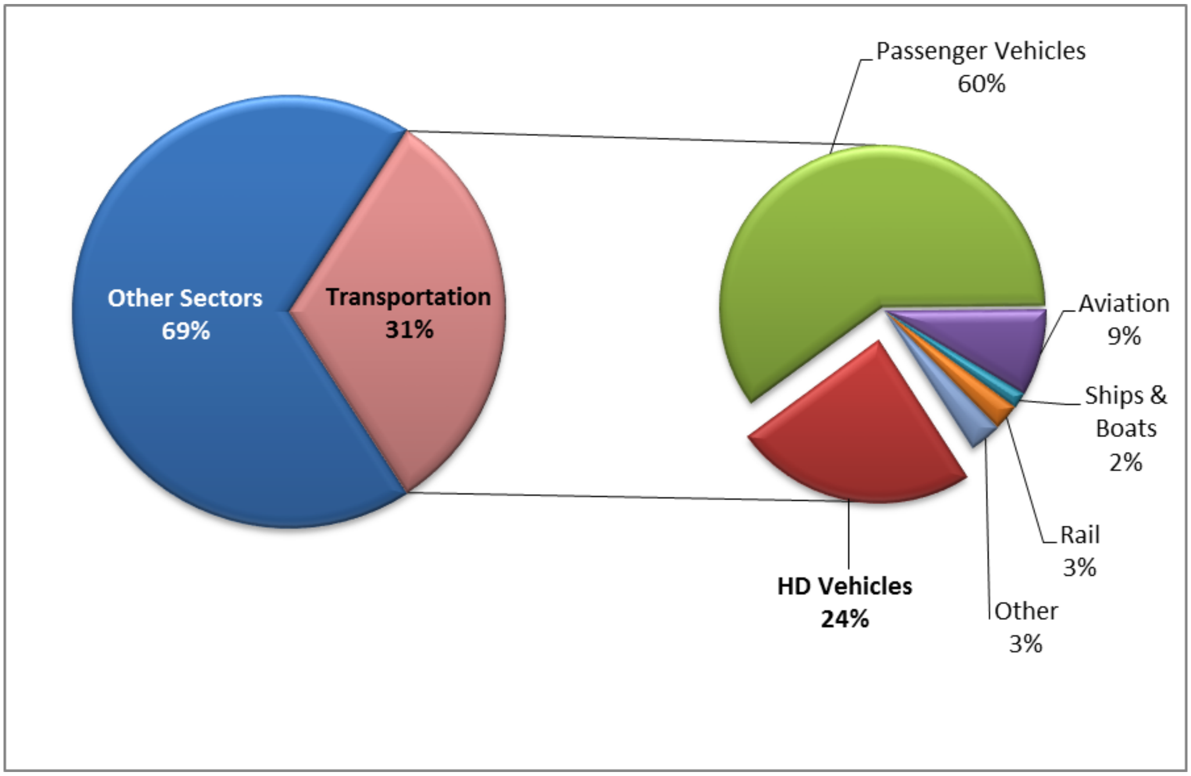
Increased concentrations of CO_2 in the atmosphere can also stimulate plant growth to some degree, a phenomenon known as the CO_2 fertilization effect. The available evidence indicates that different plants respond in different ways to enhanced CO_2 concentrations under varying climatic conditions.

Contribution of the U.S. Transportation Sector to U.S. and Global CO_2 Emissions

Contributions to the buildup of CO_2 and other 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 15.1 percent of total global CO_2 emissions (according to the World Resources Institute's Climate Analysis Indicators Tool).

As shown in Figure S-7, the U.S. transportation sector accounted for 31.3 percent of total U.S. CO_2 emissions in 2014, with HD vehicles accounting for 24.2 percent of total U.S. CO_2 emissions from transportation. Therefore, approximately 7.6 percent of total U.S. CO_2 emissions were from HD vehicles. These U.S. HD vehicles account for 1.1 percent of total global CO_2 emissions, based on the comprehensive global CO_2 emissions data available for 2012 (WRI 2016).

Figure S-7. Contribution of Transportation to U.S. CO_2 Emissions and Proportion Attributable by Mode, 2014



Source: EPA 2016c. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014. EPA 430-R-16-002.

Key Findings for Climate

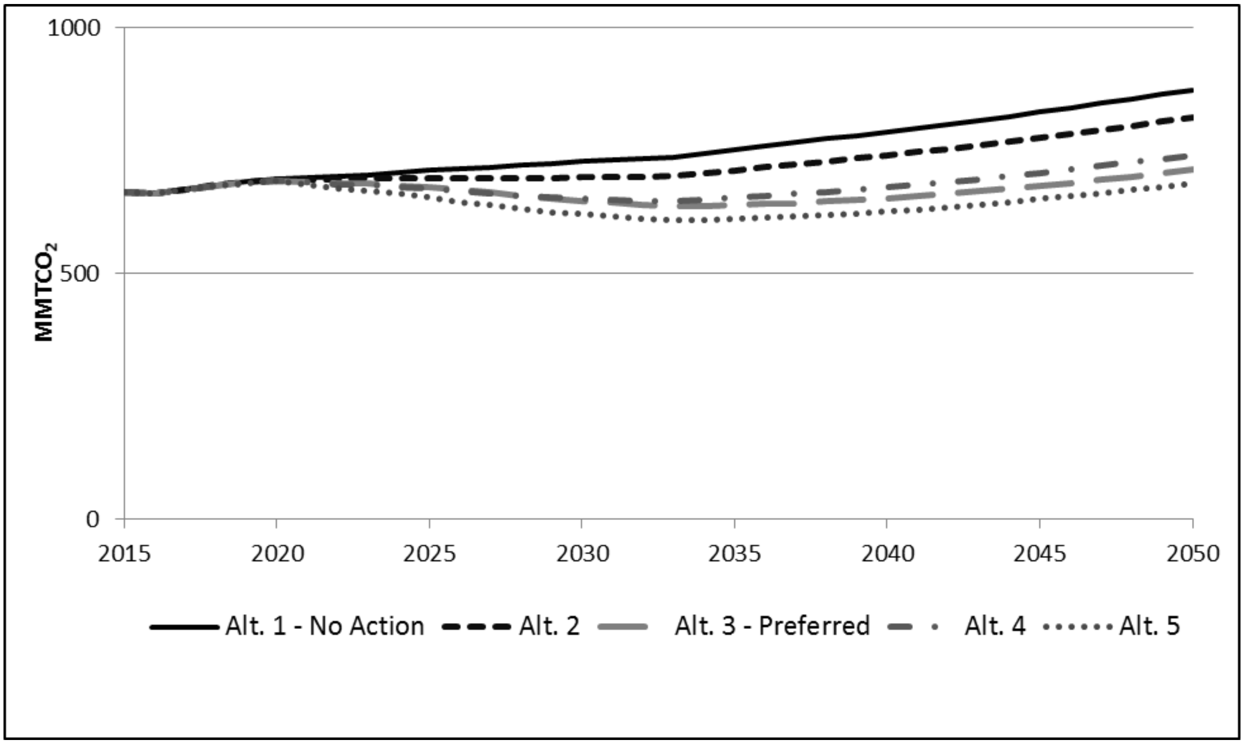
The action alternatives would decrease the growth in global GHG emissions compared with the No Action Alternative, resulting in reductions in the anticipated increases in CO_2 concentrations, temperature, precipitation, and sea level that would otherwise occur. They would also, to a small degree, reduce the impacts and risks of climate change.

Under the No Action Alternative, total CO_2 emissions from HD vehicles in the United States will increase substantially between 2018 and 2100.[2] Growth in the number of HD vehicles in use throughout the United States, combined with assumed increases in their average use, is projected to result in growth in VMT. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles.

NHTSA estimates that the action alternatives will reduce fuel consumption and CO_2 emissions compared with what they would be in the absence of the standards (i.e., fuel consumption and CO_2 emissions under the No Action Alternative) (Figure S-8).

[2] Because CO_2 accounts for such a large fraction of total GHGs emitted during fuel production and use—more than 97 percent, even after accounting for the higher GWPs of other GHGs—NHTSA's consideration of GHG impacts focuses on reductions in CO_2 emissions expected under the action alternatives.

Figure S-8. Projected Annual CO_2 Emissions ($MMTCO_2$) from All HD Vehicles by Alternative, Direct and Indirect Impacts



The global emissions scenario used in the cumulative impacts analysis (and described in Chapter 5 of this EIS) differs from the global emissions scenario used for climate change modeling of direct and indirect impacts. In the cumulative impacts 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 impacts assumes that no significant global controls on GHG emissions will be adopted. *See* Section 5.3.3.3.2 of the EIS for more explanation of the cumulative impacts methodology.

Estimates of GHG emissions and reductions (direct and indirect impacts and cumulative impacts) are presented below for each of the five alternatives. Key climate effects, such as mean global increase in surface temperature and sea-level rise, which result from changes in GHG emissions, are also presented for each of the five alternatives. These effects are typically modeled to 2100 or longer because of the amount of time required for the climate system to show the effects of the GHG emissions reductions. This inertia reflects primarily the amount of time required for the ocean to warm in response to increased radiative forcing.

The impacts of the action 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 because of the global and multi-sectoral nature of the climate problem. Although these effects are small, they occur on a global scale and are long lasting; therefore, in aggregate, they can have large consequences for health and welfare and can make an important contribution to reducing the risks associated with climate change.

Direct and Indirect Impacts

<u>Greenhouse Gas Emissions</u>

- HD vehicles are projected to emit 67,500 million metric tons of carbon dioxide ($MMTCO_2$) in the period 2018–2100 under the No Action Alternative. Alternative 2 would reduce these emissions by 6 percent by 2100, the Preferred Alternative by 16 percent, Alternative 4 by 13 percent, and Alternative 5 by 19 percent. Figure S-8 shows projected annual CO_2 emissions from HD vehicles under each alternative. As shown in the figure, emissions are highest under the No Action Alternative, while Alternatives 2 through 5 show increasing reductions in emissions compared with emissions under the No Action Alternative (with the exception of Alternative 4, which would have lower emissions reductions than the Preferred Alternative for certain analysis years).
- Compared with total projected CO_2 emissions of 801 $MMTCO_2$ from all HD vehicles under the No Action Alternative in 2100, the action alternatives are expected to reduce CO_2 emissions from HD vehicles in 2100 by 6 percent under Alternative 2, 18 percent under the Preferred Alternative, 15 percent under Alternative 4, and 22 percent under Alternative 5.
- Compared with total global CO_2 emissions from all sources of 5,063,078 $MMTCO_2$ under the No Action Alternative from 2018 through 2100, the action alternatives are expected to reduce global CO_2 emissions between 0.1 and 0.3 percent by 2100.

The emissions reductions in 2025 under each of the action alternatives compared with emissions under the No Action Alternative are approximately equivalent to the annual emissions from 0.5 million HD vehicles under Alternative 2, 1.1 million HD vehicles under the Preferred Alternative, 1.2 million HD vehicles under Alternative 4, and 1.8 million HD vehicles under Alternative 5.

<u>CO_2 Concentration, Global Mean Surface Temperature, Sea-Level Rise, and Precipitation</u>

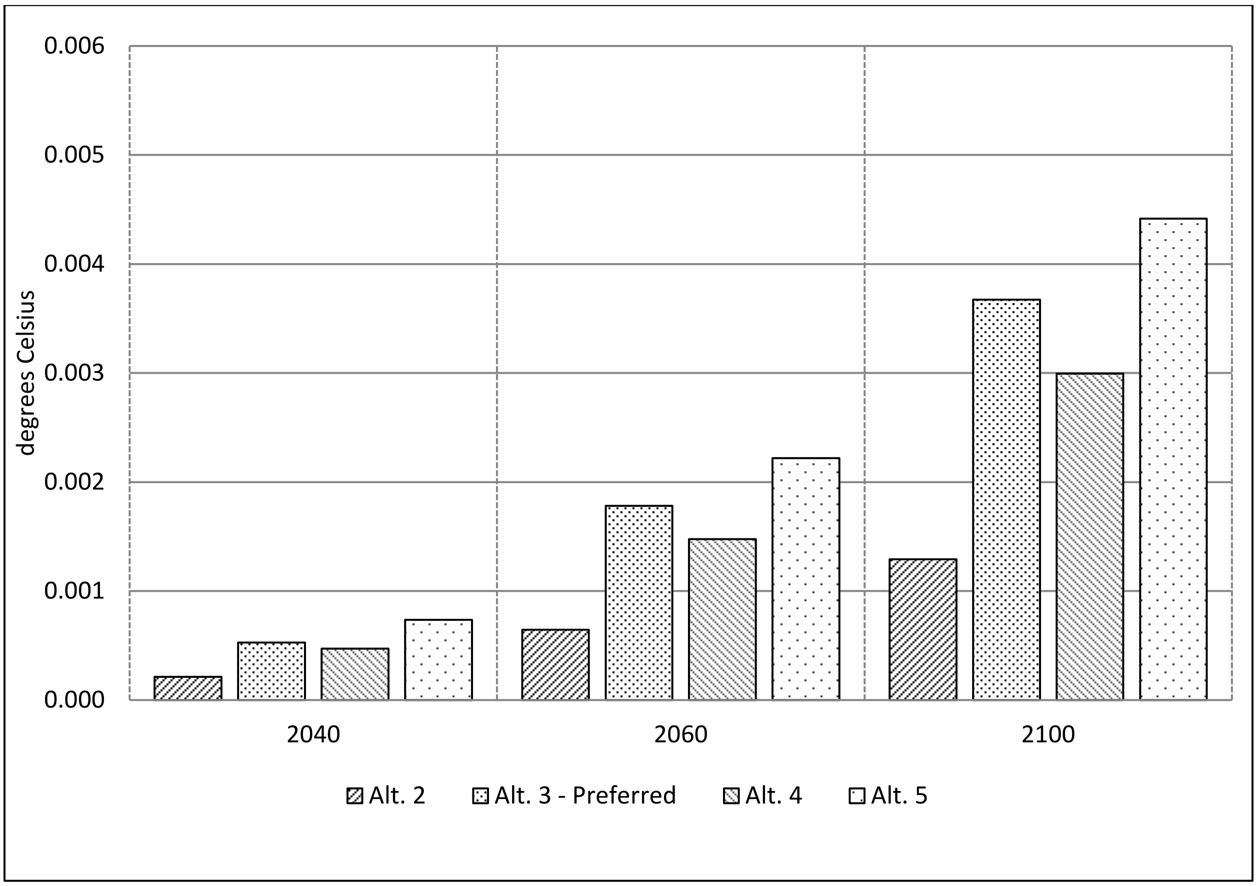
CO_2 emissions affect the concentration of CO_2 in the atmosphere, which in turn affects global temperature, sea level, and precipitation patterns. For the analysis of direct and indirect impacts, NHTSA used the Global Change Assessment Model Reference scenario (*see* Section 5.3.3.3.1 of this EIS for more details) to represent the Reference Case emissions scenario (i.e., future global emissions assuming no additional climate policy).

- Estimated CO_2 concentrations in the atmosphere for 2100 would range from 788.0 parts per million (ppm) under Alternative 5 to approximately 789.1 ppm under the No Action Alternative, indicating a maximum atmospheric CO_2 reduction of approximately 1.1 ppm compared to the No Action Alternative. The Preferred Alternative would reduce global CO_2 concentrations by approximately 1.0 ppm from CO_2 concentrations under the No Action Alternative.
- Global mean surface temperature is anticipated to increase by approximately 3.48°C (6.27°F) under the No Action Alternative by 2100. Implementing the most stringent alternative (Alternative 5) would reduce this projected temperature increase by 0.004°C (0.008°F), while implementing the least stringent alternative (Alternative 2) would reduce projected temperature increase by up to 0.001°C (0.002°F). The Preferred Alternative would decrease projected temperature increase under the No Action Alternative by 0.004°C (0.008°F). Figure S-9 shows the reduction in projected global

mean surface temperature under each action alternative compared with temperatures under the No Action Alternative.

- Projected sea-level rise in 2100 ranges from a high of 76.28 centimeters (30.03 inches) under the No Action Alternative to a low of 76.19 centimeters (30.00 inches) under Alternative 5. Therefore, the most stringent alternative would result in a maximum reduction in sea-level rise equal to 0.09 centimeter (0.03 inch) by 2100 compared with the level projected under the No Action Alternative. Sea-level rise under the Preferred Alternative would be reduced by 0.07 centimeter (0.03 inch) compared with the No Action Alternative.
- Global mean precipitation is anticipated to increase by 5.85 percent by 2100 under the No Action Alternative. Under the action alternatives, this increase in precipitation would be reduced by less than 0.01 percent.

Figure S-9. Reduction in Global Mean Surface Temperature Compared with the No Action Alternative, Direct and Indirect Impacts

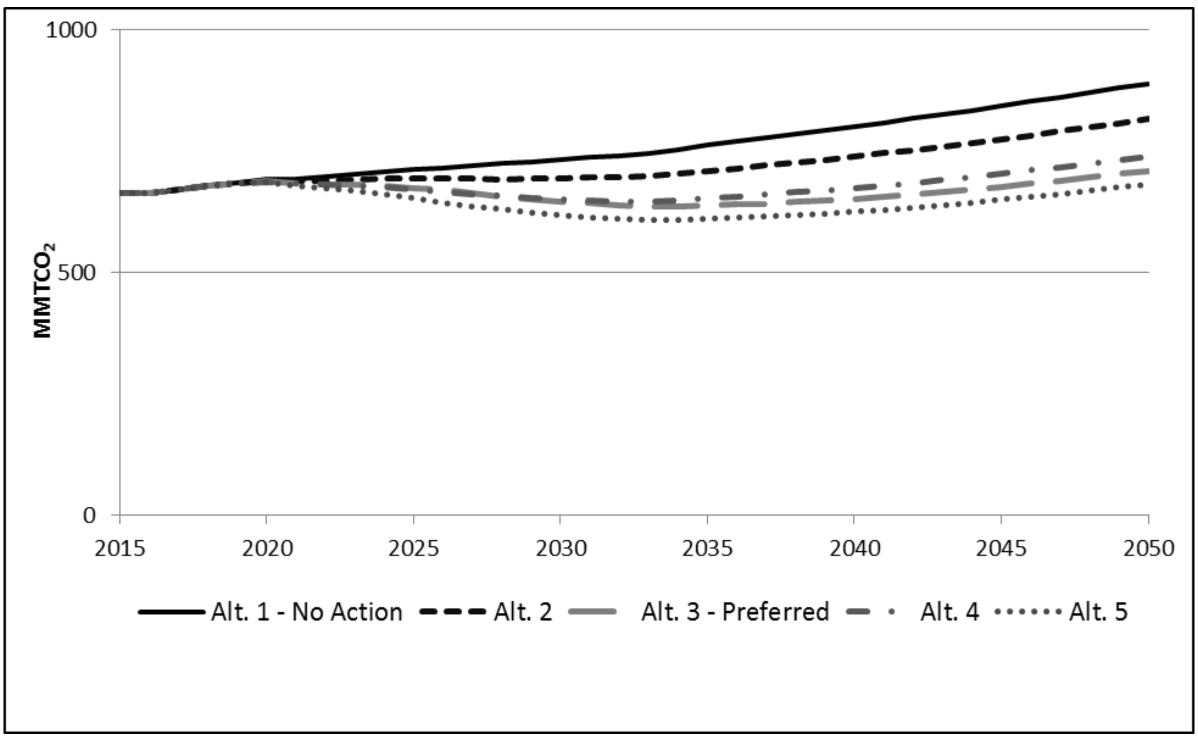


Cumulative Impacts

Greenhouse Gas Emissions

- Projections of total emissions reductions over the 2018–2100 period under the action alternatives and other reasonably foreseeable future actions (i.e., forecast HD vehicle fuel efficiency increases resulting from market-driven demand) compared with the No Action Alternative range from 5,000 $MMTCO_2$ (under Alternative 2) to 14,200 $MMTCO_2$ (under Alternative 5). Falling between these two extremes, the Preferred Alternative would reduce emissions by 12,100 $MMTCO_2$. The action alternatives would reduce total HD vehicle emissions by between 7 percent (under Alternative 2) and 21 percent (under Alternative 5) by 2100. Again falling between these two extremes, the Preferred Alternative would reduce total HD vehicle emissions by 18 percent by 2100. Figure S-10 shows projected annual CO_2 emissions from HD vehicles by alternative compared with the No Action Alternative.
- Compared with projected total global CO_2 emissions of 4,154,831 $MMTCO_2$ from all sources from 2018–2100, the incremental impact of this rulemaking is expected to reduce global CO_2 emissions between 0.1 and 0.3 percent by 2100.

Figure S-10. Projected Annual CO_2 Emissions ($MMTCO_2$) from HD Vehicles by Alternative, Cumulative Impacts

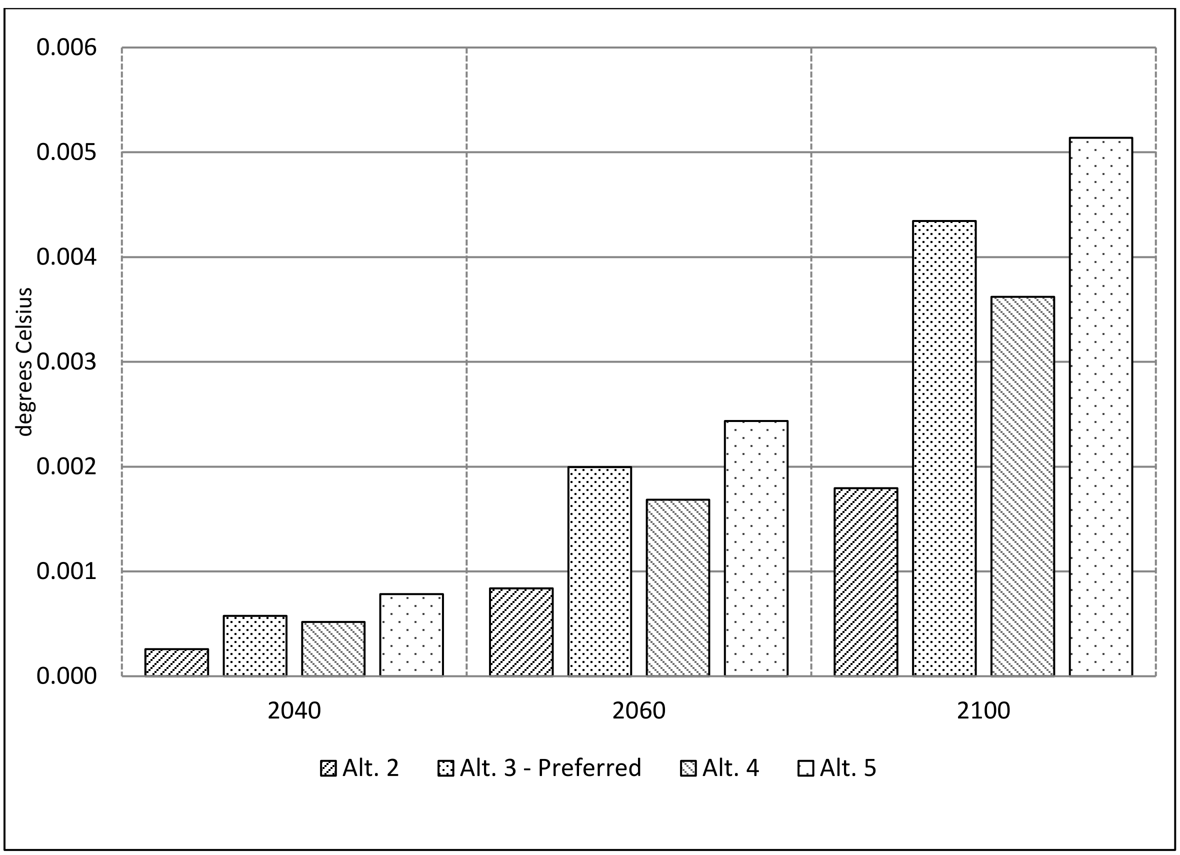


CO_2 Concentration, Global Mean Surface Temperature, Sea-Level Rise, and Precipitation

- Estimated atmospheric CO_2 concentrations in 2100 range from a low of 686.1 ppm under Alternative 5 to a high of 687.3 ppm under the No Action Alternative. The Preferred Alternative would result in CO_2 concentrations of 686.3 ppm, a reduction of 1.0 ppm compared with the No Action Alternative.
- The reduction in global mean temperature increase for the action alternatives compared with the No Action Alternative in 2100 ranges from a low of 0.002°C (0.004°F) under Alternative 2 to a high of 0.005°C (0.009°F) under Alternative 5. The Preferred Alternative would result in a reduction of 0.004°C (0.007°F) from the projected temperature increase of 2.838°C (5.108°F) under the No Action Alternative. Figure S-11 illustrates the reductions in the increase in global mean temperature under each action alternative compared with the No Action Alternative.
- Projected sea-level rise in 2100 ranges from a high of 70.22 centimeters (27.65 inches) under the No Action Alternative to a low of 70.12 centimeters (27.61 inches) under Alternative 5, indicating a maximum reduction of sea-level rise equal to 0.10 centimeter (0.04 inch) by 2100 from the level that could occur under the No Action Alternative. Sea-level rise under the Preferred Alternative would be 70.14 centimeters (27.62 inches), a 0.09-centimeter (0.04-inch) reduction compared with the No Action Alternative.

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

Figure S-11. Reduction in Global Mean Surface Temperature Compared with 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 action alternative (Alternative 5) by the year 2100 is roughly 1.2 ppm less CO_2, a few thousandths of a degree difference in temperature increase, a small percentage change in the rate of precipitation increase, and about 1 millimeter (0.03 inch) of sea-level rise. Although the projected reductions in CO_2 and climate effects are small compared with total projected future climate change, they are quantifiable and directionally consistent and would represent an important contribution to reducing the risks associated with climate change. Although NHTSA does quantify the reductions in monetized damages that can be 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 the EIS. Section 5.6 discusses the changes in non-climate impacts (such as ocean acidification by CO_2) associated with the alternatives.

CHAPTER 1 PURPOSE AND NEED FOR THE ACTION

1.1 Introduction

The Energy Policy and Conservation Act of 1975 (EPCA)[1] mandated that the National Highway Traffic Safety Administration (NHTSA) establish and implement a regulatory program for motor vehicle fuel economy.[2] As codified in Chapter 329 of Title 49 of the U.S. Code (U.S.C.), and as amended by the Energy Independence and Security Act of 2007 (EISA),[3] EPCA sets forth specific requirements concerning the establishment of average fuel economy standards for passenger cars and light trucks, which are motor vehicles with a gross vehicle weight rating (GVWR) less than 8,500 pounds and medium-duty passenger vehicles with a GVWR less than 10,000 pounds.[4] This regulatory program, known as the Corporate Average Fuel Economy Program (CAFE), was established to reduce national energy consumption by increasing the fuel economy of these automobiles.

EISA was enacted in December 2007, providing the U.S. Department of Transportation (DOT)—and NHTSA, by delegation—new authority to implement, via rulemaking and regulations, "a commercial medium- and heavy-duty on-highway vehicle[5] and work truck[6] fuel efficiency improvement program designed to achieve the maximum feasible improvement" for motor vehicles with a GVWR of 8,500 pounds or greater, except for medium-duty passenger vehicles already covered under CAFE.[7] This broad sector—ranging from large pickups to sleeper-cab tractors—represents the second-largest contributor to oil consumption and greenhouse gas (GHG) emissions from the transportation sector, after light-duty passenger cars and trucks. EISA directs NHTSA to "adopt and implement appropriate test methods, measurement metrics, fuel economy standards, and compliance and enforcement protocols that are appropriate, cost-effective, and technologically feasible for commercial medium- and heavy-duty on-highway vehicles and work trucks."[8] This authority permits NHTSA to set "separate standards for different classes of vehicles."[9] Commercial medium-duty and heavy-duty on-highway vehicles and work

[1] Pub. L. No. 94-163, 89 Stat. 871 (Dec. 22, 1975). EPCA was enacted to serve the United States' energy demands and promote energy conservation when feasibly obtainable.

[2] EPCA directs the Secretary of Transportation to set and implement fuel economy standards for passenger cars and light trucks sold in the United States. The Secretary has delegated responsibility for implementing EPCA fuel economy requirements to NHTSA. 49 CFR §§ 1.95, 501.2.

[3] Pub. L. No. 110-140, 121 Stat. 1492 (Dec. 19, 2007). EISA amends and builds on EPCA by setting out a comprehensive energy strategy for the 21st century, including the reduction of fuel consumption from all motor vehicle sectors.

[4] 49 U.S.C. §§ 32901(a)(3), (a)(17)-(19).

[5] EISA added the following definition to the U.S.C. automobile fuel economy chapter: "commercial medium- and heavy-duty on-highway vehicle" means an on-highway vehicle with a gross vehicle weight rating of 10,000 pounds or more. 49 U.S.C. § 32901(a)(7).

[6] EISA added the following definition to the U.S.C. automobile fuel economy chapter: "work truck" means a vehicle that – (A) is rated at between 8,500 and 10,000 pounds gross vehicle weight; and (B) is not a medium-duty passenger vehicle (MDPV) (as defined in section 86.1803–01 of title 40, Code of Federal Regulations, as in effect on the date of the enactment of [EISA]). 49 U.S.C. § 32901(a)(19).

[7] 49 U.S.C. § 32902(k)(2).

[8] *Id*.

[9] *Id*.

trucks, including their engines and certain trailers, are hereinafter referred to collectively as "HD vehicles."[10] EISA also provides for regulatory lead time and regulatory stability. EISA dictates that the HD Fuel Efficiency Improvement Program NHTSA implements must provide not fewer than 4 full model years of regulatory lead time and 3 full model years of regulatory stability.[11]

Consistent with these requirements and in consultation with the U.S. Environmental Protection Agency (EPA) and Department of Energy (DOE), NHTSA established the first fuel efficiency standards for HD vehicles in September 2011, as part of a comprehensive HD National Program to reduce GHG emissions and fuel consumption for HD vehicles.[12] Those fuel efficiency standards constituted the first phase (Phase 1) of the NHTSA HD Fuel Efficiency Improvement Program. They were established to begin in model year (MY) 2016 and remain stable through MY 2018,[13] consistent with EISA's requirements. Although EISA prevented NHTSA from enacting mandatory standards before MY 2016, NHTSA established voluntary compliance standards for MYs 2014–2015 prior to mandatory regulation in MY 2016. Throughout this EIS, NHTSA refers to the rulemaking and EIS associated with the MY 2014–2018 HD vehicle fuel efficiency standards described in this paragraph as "Phase 1" or "Phase 1 HD National Program."

In February 2014, the president directed NHTSA and EPA to develop and issue the next phase of HD vehicle fuel efficiency and GHG standards, as stated in the White House's report, *Improving the Fuel Efficiency of American Trucks – Bolstering Energy Security, Cutting Carbon Pollution, Saving Money and Supporting Manufacturing Innovation* (White House 2014a). Consistent with this directive, NHTSA is establishing fuel efficiency standards for HD vehicles for MYs 2018 and beyond[14] as part of a joint

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[10] For purposes of this EIS, the term *heavy-duty* or *HD* applies to almost all on-highway engines and vehicles that are not within the range of passenger cars, light trucks, and MDPVs covered by the greenhouse gas and CAFE standards issued for model years (MY) 2017–2025. The term also does not include motorcycles. In addition, for the purpose of this EIS, this term includes recreational vehicles, which is in contrast to how this term was used in the EIS associated with the MY 2014–2018 HD vehicle fuel efficiency standards. *See* Section I.E.2.b of the Final Rule for a discussion of why NHTSA is including recreational vehicles within the scope of the HD Fuel Efficiency Improvement Program. For background on the HD vehicle segment, and fuel efficiency improvement technologies available for those vehicles, see the following reports recently issued by the National Academy of Sciences: *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles* (NAS 2010) and *Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: First Report* (NAS 2014).

[11] 49 U.S.C. § 32902(k)(3).

[12] In the context of 49 U.S.C. § 32902(k), NHTSA interprets "fuel economy standards" broadly in order to account as accurately as possible for HD vehicle fuel efficiency. The Phase 1 Final Rule explained that NHTSA opted to set the HD fuel efficiency standards using metrics other than miles per gallon to account for the work performed by various types of HD vehicles. Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule, 76 FR 57106 (Sept. 15, 2011) (hereinafter "Phase 1 Final Rule").

[13] NHTSA's Phase 1 standards for HD pickups and vans allowed manufacturers to select one of two fuel consumption standard alternatives for MY 2016 and later. The first alternative defined individual gasoline vehicle and diesel vehicle fuel consumption target curves that do not change for model years 2016–2018, and are equivalent to EPA's compliance alternative of 67–67–67–100 percent target curves in MYs 2016–2017–2018–2019, respectively. The second alternative used target curves that are equivalent to the EPA's 40–60–100 percent target curves in MYs 2016–2017–2018, respectively. These standards would have remained in effect indefinitely at their MY 2018 or 2019 levels. *See* Phase 1 Final Rule, *supra* note 12 at 57119.

[14] This Final Action establishes new standards beginning with MY 2018 for certain trailers and MY 2021 for all of the other HD vehicle categories, with stringency increases through MY 2027 for some segments. Standards will remain at the final stringency levels until amended by a future rulemaking.

rulemaking with EPA to establish the Phase 2 HD National Program (also referred to as "Phase 2"). As with Phase 1 and as directed by EISA, NHTSA has conducted the Phase 2 HD Fuel Efficiency Improvement Program rulemaking in consultation with EPA and DOE.[15]

Pursuant to the National Environmental Policy Act[16] (NEPA), 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 Phase 2 standards, pursuant to Council on Environmental Quality (CEQ) NEPA implementing regulations, DOT Order 5610.1C, and NHTSA regulations,[18] NHTSA has prepared this EIS, which analyzes, discloses, and compares the potential environmental impacts of a reasonable range of action alternatives (including a Preferred Alternative) and the No Action Alternative. The Draft EIS was issued together with the Phase 2 Notice of Proposed Rulemaking (NPRM)[19] on June 19, 2015.[20]

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.[21] The purpose of this rulemaking is to continue to promote EPCA's goals of energy independence and security, as well as to improve environmental outcomes and national security, by continuing to implement an HD Fuel Efficiency Improvement Program that is "designed to achieve the maximum feasible improvement."[22]

Congress specified that as part of the HD Fuel Efficiency Improvement Program, NHTSA must adopt and implement appropriate test methods, measurement metrics, fuel economy standards,[23] and compliance and enforcement protocols. These required aspects of the program must be appropriate, cost effective, and technologically feasible for HD vehicles. As stated previously, Congress also directed that the standards adopted under the program must provide no fewer than 4 model years of regulatory lead time and 3 model years of regulatory stability. In developing Phase 2, NHTSA has continued to consider these EISA requirements as well as relevant environmental and safety considerations.

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[15] 49 U.S.C. § 32902(k)(2).

[16] 42 U.S.C. §§ 4321–4347.

[17] 42 U.S.C. § 4332.

[18] 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.

[19] *See* Notice of Proposed Rulemaking (NPRM) for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2, 80 FR 40138 (July 13, 2015) (hereinafter "Phase 2 NPRM").

[20] NHTSA posted both the Phase 2 NPRM and the Draft EIS on its fuel economy website (www.nhtsa.gov/fuel-economy).

[21] 40 CFR § 1502.13.

[22] 49 U.S.C. § 32902(k)(2).

[23] *See* Phase 1 Final Rule, *supra* note 12, at 57115.

The 2014 White House report on improving HD vehicle fuel efficiency (White House 2014a) explained that although the standards established under the Phase 1 HD National Program have locked in long-lasting gains in fuel efficiency, HD vehicle fuel consumption is still projected to grow as more trucks are driven more miles. For this reason, the White House report explained that new standards extending beyond Phase 1 are needed to further improve energy security, save money for consumers and businesses, reduce harmful air pollution, and lower costs for transporting goods. President Obama's May 29, 2014, *All-of-the-Above Energy Strategy* similarly stated that the development of Phase 2 HD fuel efficiency standards "will lead to large savings in fuel, lower CO_2 [carbon dioxide] emissions, and health benefits from reduced particulate matter and ozone" (White House 2014b). To develop standards that provide long-term certainty and promote innovation, the White House directed NHTSA and EPA to work closely with both large and small stakeholders to explore further opportunities for fuel consumption and emissions reductions beyond MY 2018.[24] The president also directed NHTSA and EPA to consult with the California Air Resources Board (CARB) to ensure that the next phase of standards allows manufacturers to continue to build a single national fleet.[25] Additionally, the report directed NHTSA and EPA to consider the following advanced technologies, some of which may not currently be in production:

- Engine and powertrain efficiency improvements
- Aerodynamics
- Weight reduction
- Improved tire rolling resistance
- Hybridization
- Automatic engine shutdown
- Accessory improvements (e.g., water pumps, fans, auxiliary power units, air conditioning)

The Final Action and alternatives analyzed in this EIS have been developed to reflect the purpose and need specified by EPCA, EISA, the Phase 1 HD National Program, and the president's directive to develop and issue these standards (White House 2014a).

1.3 National Environmental Policy Act and Joint Rulemaking Process

Together with the Draft EIS, NHTSA and EPA issued proposed rules to establish Phase 2 fuel efficiency and GHG emissions standards for HD vehicles.[26] NHTSA is issuing this Final EIS concurrently with the Final Rule (Record of Decision), pursuant to 49 U.S.C. 304a (Pub. L. No. 114-94, 129 Stat. 1312, Section 1311(a)) and U.S. Department of Transportation *Final Guidance on MAP-21 Section 1319 Accelerated Decisionmaking in Environmental Reviews*.[27] The Final Rule addresses the urgent and closely intertwined challenges of energy independence and security and climate change by continuing strong and coordinated federal fuel efficiency and GHG emissions standards for HD vehicles through the HD

[24] *Id.* at 8.

[25] *Id*.

[26] The agencies' notices of proposed rulemaking were published in a single *Federal Register* notice as a coordinated, joint proposal. *See* Phase 2 NPRM, *supra* note 19.

[27] The Department's guidance is posted online at http://www.dot.gov/sites/dot.gov/files/docs/MAP-21_1319_Final_Guidance.pdf.

National Program. The rule achieves substantial reductions in fuel consumption and GHG emissions from the HD vehicle sector. The rule builds on the first phase of the HD National Program, established by a joint rule issued by NHTSA and EPA in September 2011, in which NHTSA set fuel efficiency standards and EPA set GHG emissions standards for MY 2014–2018 and beyond HD vehicles (Phase 1 HD National Program).[28] The Phase 2 HD National Program has the potential to deliver additional environmental and energy benefits, cost savings, and administrative efficiencies nationwide using a coordinated approach.

1.3.1 Building Blocks of the National Program

The HD National Program is both needed and possible because there is a direct relationship between improving fuel efficiency and reducing CO_2 tailpipe emissions. The amount of CO_2 emissions is essentially constant per gallon combusted of a given type of fuel. The more fuel efficient a vehicle, the less fuel it burns performing a given amount of work across a given distance. The less fuel it burns, the less CO_2 it emits in performing that work across that distance. While there are emissions control technologies that reduce the pollutants (e.g., carbon monoxide) produced by imperfect combustion of fuel by capturing or destroying them, there is currently no such technology for CO_2. Emissions control technologies for CO_2, therefore, depend on reducing the quantity of fuel consumed. As a result, the same technologies address the twin problems of reducing fuel consumption and reducing CO_2 emissions.

1.3.1.1 DOT's HD Vehicle Fuel Efficiency Improvement Program

With the passage of EISA in December 2007, Congress provided a framework for developing the first fuel efficiency regulations for HD vehicles. In September 2011, NHTSA issued a rule establishing the Phase 1 fuel efficiency standards for HD vehicles in accordance with the EISA mandate to establish an HD "fuel efficiency improvement program designed to achieve the maximum feasible improvement."[29] In Phase 1, NHTSA set mandatory standards for HD vehicles beginning in MY 2016 and voluntary compliance standards for MY 2014–2015 HD vehicles. NHTSA set fuel efficiency standards for the following three categories of commercial medium- and heavy-duty on-highway vehicles and work trucks (and the engines that power them) based on the relative degree of homogeneity among trucks within each category: HD pickups and vans, vocational vehicles, and combination tractors. These vehicle categories are described in greater detail in the discussion of the Final Action in Section 1.3.2. Phase 2 builds off of Phase 1, establishing mandatory fuel efficiency standards for HD vehicles for MYs 2018 and beyond. Section 1.3.2 discusses the Phase 2 Final Rule, including differences between Phase 1 and Phase 2. For example, while Phase 1 deferred action on setting standards for commercial trailers,[30] Phase 2 regulates such trailers.

1.3.1.2 EPA's Greenhouse Gas Standards for HD Vehicles

Since the 1980s, EPA has acted several times to address tailpipe emissions of criteria pollutants and air toxics from HD vehicles under its Clean Air Act (CAA) authority. Prior to the HD National Program established in September 2011, these programs have primarily addressed emissions of ozone precursors (hydrocarbons and nitrogen oxides [NO_x] and particulate matter [PM]). Under Phase 1, EPA issued GHG emissions standards for the same three classes of commercial medium- and heavy-duty on-highway

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[28] *See* Phase 1 Final Rule, *supra* note 12.

[29] 49 U.S.C. § 32902(k)(2); Phase 1 Final Rule, *supra* note 12.

[30] *See* Phase 1 Final Rule, *supra* note 12, at 57111 ("While we are deferring action today on setting trailer standards, the agencies are committed to moving forward to create a regulatory program for trailers that would complement the current vehicle program.").

vehicles and work trucks (HD pickups and vans, vocational vehicles, and combination tractors) and engines.

One difference between the EPA GHG standards and NHTSA fuel efficiency standards under the HD National Program relates to when the standards apply. As required by the CAA, EPA mobile source emissions standards apply at the time the vehicle or engine is sold, as well as when the vehicle is in actual use. This is in contrast to the NHTSA fuel consumption standards under EISA, which apply only at the time the vehicle or engine is sold.

A second difference between the EPA GHG emissions standards and the NHTSA fuel efficiency standards is that the EPA standards regulate hydrofluorocarbons (HFCs), which is a GHG of concern that could leak from vehicle air conditioning systems, but is not related to fuel efficiency. Specifically, in Phase 1, EPA established separate air conditioning refrigerant leakage standards for combination tractors and for HD pickups and vans. EPA did not adopt air conditioning refrigerant leakage standards for vocational vehicles.[31] However, for Phase 2, EPA is adopting similar standards for vocational vehicles, beginning in MY 2021.[32] The process for certifying that low leakage components are used would follow the system currently in place for comparable systems in tractors.[33]

1.3.1.3 California Air Resources Board (CARB) Greenhouse Gas Program

CARB sets motor vehicle emissions standards for the State of California. In Phase 1, NHTSA and EPA worked with a diverse group of stakeholders, including the State of California. As explained in the Phase 1 Final Rule, based on the agencies' ongoing consultation with CARB, NHTSA and EPA expected that CARB would be able to adopt regulations equivalent in practice to those of the HD National Program, just as it had done for past EPA regulation of HD trucks and engines. On December 5, 2014, California approved CARB's Phase 1 GHG regulations, which aligned California's GHG emissions standards and test procedures with the Phase 1 HD National Program.[34] President Obama directed NHTSA and EPA to continue to consult with CARB to ensure that the next phase of standards allows manufacturers to continue to build a single national fleet (White House 2014a).

1.3.1.4 Light-Duty National Program

In 2010, NHTSA and EPA set fuel economy and GHG emissions standards for MY 2012–2016 passenger cars and light trucks (collectively, "light-duty vehicles").[35] In 2012, the agencies established the fuel economy and GHG emissions standards for light-duty vehicles for MYs 2017 and beyond.[36] In certain respects, the agencies used the Light-Duty National Program as a model for the HD National Program, including NHTSA's Phase 2 HD fuel efficiency standards. This is most apparent in the case of medium-duty pickups and vans, which are very similar to the light-duty trucks addressed in the Light-Duty National Program both technologically and in terms of how they are manufactured (i.e., the same

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[31] *See* Section II.E.5 of the Phase 1 Final Rule, *supra* note 12.

[32] *See* Section V of the Phase 2 Final Rule.

[33] *See* Section V of the Phase 2 Final Rule.

[34] CARB. 2013. Heavy-Duty GHG Phase 1: Final Approval of Notice. Available at: http://www.arb.ca.gov/regact/2013/hdghg2013/hdghg2013.htm.

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

[36] 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule, 77 FR 62624 (Oct. 15, 2012).

company often makes both the vehicle and the engine). For these vehicles, there are close parallels to the Light-Duty National Program in how the agencies have developed standards and compliance structures, although for this current rule, each agency is finalizing standards based on attributes other than vehicle footprint, as discussed in Section 1.3.2.

Due to the diversity of the remaining HD vehicles, there are fewer parallels with the structure of the Light-Duty National Program. The agencies, however, have maintained the same collaboration and coordination that characterized the development of the Light-Duty National Program. Most notably, manufacturers will be able to design and build to meet the requirements of a closely coordinated federal program and avoid unnecessarily duplicative testing and compliance burdens.

1.3.2 Final Action

NHTSA's Final Action is to set HD vehicle fuel efficiency standards, in accordance with the EISA mandate to "implement a commercial medium- and heavy-duty on-highway vehicle and work truck fuel efficiency improvement program."[37] As part of a joint rulemaking effort, NHTSA and EPA are finalizing coordinated fuel consumption[38] and GHG emissions standards for HD vehicles to be built in MYs 2018 and beyond. Reducing HD vehicle fuel consumption and GHG emissions requires increasing the inherent efficiency of the engine and reducing the work that needs to be done per mile traveled. This objective requires a focus on the entire vehicle. For example, in addition to the basic emissions and fuel consumption levels of the engine, the aerodynamics of the vehicle can have a major impact on the amount of work that must be performed to transport freight. The National Academy of Sciences (NAS) recommended this focus on both the engine and the rest of the vehicle in its reports, *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles* (NAS 2010) and *Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicle, Phase Two* (NAS 2014). The Phase 2 HD vehicle fuel efficiency standards that make up the HD National Program aim to address the complete vehicle, to the extent practicable and appropriate under the agencies' respective statutory authorities, through complementary engine and vehicle standards.

1.3.2.1 HD Vehicle Categories Covered by the Phase 2 Standards

NHTSA's HD vehicle fuel efficiency standards (including both the Phase 1 standards and the final Phase 2 standards as described in this EIS) apply to nearly all[39] commercial highway engines and vehicles that are not regulated by the light-duty passenger car, light-duty truck, and medium-duty passenger vehicle (MDPV) CAFE and GHG standards issued for MY 2017 and beyond. Thus, the HD Fuel Efficiency Improvement Program, unless otherwise specified, covers all vehicles rated at a GVWR greater than 8,500 pounds (except for MDPVs) and the engines that power these vehicles. EISA Section 103(a)(3)

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[37] 49 U.S.C. § 32902(k)(2).

[38] NHTSA's action is to set fuel consumption standards, as opposed to the fuel economy standards that the agency sets under the CAFE program for light-duty vehicles. Whereas fuel economy measures the distance a vehicle can travel with a gallon of fuel, and is expressed in miles per gallon, fuel consumption is the inverse metric—the amount of fuel consumed in driving a given distance (NAS 2010). Fuel consumption is a useful measurement because it is directly related to the goal of decreasing the amount of fuel necessary for an HD vehicle to travel a given distance. Fuel consumption standards satisfy EISA's directive that NHTSA implement a fuel efficiency improvement program because the more efficient an HD vehicle is in completing its work, the less fuel it will consume to move cargo a given distance.

[39] The agencies exclude a small number of vehicles that would otherwise meet the definition of a commercial medium- and heavy-duty on-highway vehicle.

defines a "commercial medium- and heavy-duty on-highway vehicle" as an on-highway vehicle with a GVWR of 10,000 pounds or more.[40] EISA Section 103(a)(6) defines a "work truck" as a vehicle that is rated at between 8,500 and 10,000 pounds gross vehicle weight and is not an MDPV.[41] Therefore, in NHTSA's HD Fuel Efficiency Improvement Program and in this EIS, the term *HD vehicles* refers to both work trucks and commercial medium- and heavy-duty on-highway vehicles, as defined by EISA. In addition, for the purpose of this EIS, this term includes recreational vehicles, which is in contrast to how this term was used in the Phase 1 EIS.[42]

NHTSA's HD Fuel Efficiency Improvement Program (including the final Phase 2 standards) applies to HD engines, which are generally those installed in commercial medium- and heavy-duty trucks. This term excludes engines installed in vehicles certified to a complete vehicle emissions standard based on a chassis test, because these are addressed as a part of those complete vehicles. It also excludes engines used exclusively for stationary power when the vehicle is parked. In addition to regulating HD engines, in the Phase 1 Final Rule, NHTSA and EPA established standards for each of three different categories of HD vehicles, which together comprise the range of HD vehicles available.

The Phase 2 HD Fuel Efficiency Improvement Program described in this EIS follows the same general categories with a few exceptions.

- **Combination tractors (Classes 7–8):** Heavy-duty combination trucks are built to move freight. The ability of a truck to meet a customer's freight transportation requirements depends on three major characteristics of the tractor: the GVWR (which along with gross combined weight rating [GCWR] establishes the maximum carrying capacity of the tractor and trailer), cab type (sleeper cabs provide overnight accommodations for drivers), and the tractor roof height (to mate tractors to trailers for the most fuel-efficient configuration). Each of these attributes affects the baseline fuel consumption and GHG emissions, as well as the effectiveness of possible technologies like aerodynamics, and is discussed in Section III.A of the Phase 1 Final Rule. Class 7 trucks, which have a GVWR of 26,001 to 33,000 pounds and a typical GCWR of 65,000 pounds, have a lesser payload capacity[43] than Class 8 trucks. Class 8 trucks have a GVWR of greater than 33,000 pounds and a typical GCWR of 80,000 pounds. The Phase 2 standards for heavy-haul tractors apply to tractors with a GCWR over 120,000 pounds. As discussed in Section IX of the Phase 1 Final Rule, the finalized fuel consumption and GHG emissions standards did not regulate trailers. However, as discussed in Section 1.3.2.2, below, NHTSA and EPA will regulate certain trailers used in combination with HD tractors as a part of the Phase 2 HD National Program.

[40] *Codified at* 49 U.S.C. § 32901(a)(7).

[41] *Codified at* 49 U.S.C. § 32901(a)(19). EPA defines medium-duty passenger vehicles as any complete vehicle between 8,500 and 10,000 pounds GVWR designed primarily for the transportation of persons that meet the criteria outlined in 40 CFR § 86.1803-01. The definition specifically excludes any vehicle that (1) has a capacity of more than 12 persons total or (2) is designed to accommodate more than 9 persons in seating rearward of the driver's seat or (3) has a cargo box (e.g., pickup box or bed) of 6 feet or more in interior length. *See* Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Final Rule, 65 FR 6698 (Feb. 10, 2000).

[42] *See* Section I of the Final Rule for a discussion of why NHTSA is including recreational vehicles within the scope of the Phase 2 Fuel Efficiency Improvement Program.

[43] Payload is determined by a tractor's GVWR and GCWR relative to the weight of the tractor, trailer, fuel, driver, and equipment.

- **HD pickups and vans (Classes 2b–3):** HD vehicles with a GVWR of 8,501 to 10,000 pounds are classified in the industry as Class 2b motor vehicles. As discussed above, Class 2b includes MDPVs that the agencies regulate under the light-duty vehicle program, and the HD National Program established in the Phase 1 Final Rule did not include additional requirements for MDPVs. HD vehicles with GVWR of 10,001 to 14,000 pounds are classified as Class 3 motor vehicles. The HD National Program regulates Classes 2b–3 HD vehicles (referred to in the EIS as HD pickups and vans) together using an approach similar to that used in the current CAFE program and the EPA GHG emissions standards for light-duty vehicles.
- **Vocational Vehicles (Classes 2b–8):** Classes 2b–8 vocational vehicles consist of a very wide variety of configurations including delivery, refuse, utility, dump, tow, and cement trucks; transit, shuttle, and school buses; emergency vehicles; and motor homes, among others. The HD National Program defines Classes 2b–8 vocational vehicles as all HD vehicles not included in HD pickups and vans or Classes 7–8 tractor segments.

Table 1.3.2-1 outlines how GVWR classes correspond to the HD vehicle categories of pickups and vans, vocational vehicles, and tractors. For Phase 2, the agencies are also setting standards for an additional subcategory for "heavy-haul" tractors designed to haul much heavier loads than conventional tractors. The typical tractor in the United States has a GCWR of up to 80,000 pounds due to the effective weight limit on the federal highway system, except in states with preexisting higher weight limits. Phase 2 standards for heavy-haul tractors apply to tractors with a GCWR over 120,000 pounds, which are not typically used in the same manner as long-haul tractors with extended highway driving.

Table 1.3.2-1. HD Vehicle Segments by Gross Vehicle Weight Rating (pounds)

Class 2b	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
8,501–10,000	10,001–14,000	14,001–16,000	16,001–19,500	19,501–26,000	26,001–33,000	>33,000
HD pickups and vans (incl. work trucks)						
Vocational vehicles (e.g., van trucks, utility "bucket" trucks, tank trucks, refuse trucks, buses, fire trucks, flat-bed trucks, and dump trucks)						
					Tractors (for combination tractor-trailers)	

1.3.2.2 Differences between Phase 1 of the HD Fuel Efficiency Improvement Program (MYs 2014–2018) and Phase 2 (MYs 2018 and Beyond)

NHTSA is issuing new fuel efficiency standards for HD vehicles that build on and enhance existing Phase 1 standards, and is introducing the first-ever standards for certain trailers used in combination with HD tractors. Classes 7–8 tractors and their trailers account for approximately two-thirds of the HD vehicle sector's total CO_2 emissions and fuel consumption. Although trailers do not directly generate exhaust emissions or consume fuels (except for the refrigeration units on refrigerated trailers), their designs and operation nevertheless contribute substantially to the CO_2 emissions and diesel fuel consumption of the tractors pulling them. The final Phase 2 trailer standards are expressed as CO_2 and fuel consumption standards, and apply to each trailer regarding the emissions and fuel consumption that would be expected for a specific standard type of tractor pulling such a trailer. NHTSA and EPA believe it is appropriate to establish standards for trailers separately from tractors because they are separately manufactured by distinct companies. The agencies did not propose standards for CO_2 emissions and fuel consumption from the transport refrigeration units (TRUs) used on refrigerated box trailers.

Additionally, EPA did not propose standards for hydrofluorocarbon (HFC) emissions from TRUs. Section IV of the Final Rule provides additional background and detail on trailer considerations and the trailer standards.

Taken together, the Phase 2 program comprises a set of technology-advancing[44] standards that should achieve greater GHG and fuel consumption savings than the Phase 1 program, predicated on use of both off-the-shelf technologies and emerging technologies that are not yet in widespread use. The agencies are issuing standards for MY 2027 that will likely require manufacturers to make extensive use of these technologies. Phase 2 will carry over many of the compliance approaches developed for Phase 1, with certain changes as described in Section I.C of the Final Rule.

Table 1.3.2-2 summarizes the difference between the Phase 1 and final Phase 2 fuel efficiency standards for HD vehicles across categories. Following Table 1.3.2-2 is a narrative summary of Phase 2 that points readers to sections of the Final Rule that contain additional detail regarding the Final Action for specific regulated categories of HD vehicles.

Table 1.3.2-2. Summary of Phase 1 and Phase 2 HD Vehicle Programs

	Phase 1 Program	Phase 2 Program
Engines installed in tractors and vocational chassis		
Share of HD vehicle fuel consumption and GHG emissions	Combination tractors and vocational vehicles account for approximately 85% of fuel use and GHG emissions in the medium and heavy duty truck sector.	
Form of the standard	Gallons of fuel/brake horsepower-hour (gal/100 bhp-hr).	
Example technology options available to help manufacturers meet standards	Combustion, air handling, friction, and emissions after-treatment technology improvements.	Increased use of Phase 1 technologies, plus waste heat recovery systems for tractor engines.
Flexibilities	ABT program that allows emissions and fuel consumption credits to be averaged, banked, or traded (5-year credit life). Manufacturers allowed to carry forward credit deficits for up to 3 model years. Interim incentives for advanced technologies, recognition of innovative (off-cycle) technologies not accounted for by the Phase 1 test procedures, and credits for certifying early.	Same as Phase 1, except no advanced technology incentives.
Tractors designed to pull trailers and move freight		
Share of HD vehicle fuel consumption and GHG emissions	Combination tractors and their engines account for approximately two-thirds of fuel use and GHG emissions in the medium and heavy duty truck sector.	
Form of the standard	Gallons of fuel/1,000 ton payload mile (gal/1,000 ton-miles).	

[44] In this context, the term "technology-advancing" means standards that will effectively require manufacturers to develop new technologies (or to significantly improve technologies), as distinguished from standards that can be met using off-the-shelf technology alone. The standards do not require manufacturers to use any specific technologies.

	Phase 1 Program	Phase 2 Program
Example technology options available to help manufacturers meet standards	Aerodynamic drag improvements, low-rolling resistance tires, engine efficiency improvements, high strength steel and aluminum weight reduction, extended idle reduction, and speed limiters.	Increased use of Phase 1 technologies, plus additional engine improvements, improved and automated transmissions, powertrain optimization, tire inflation and pressure monitoring systems, and predictive cruise control.
Flexibilities	ABT program that allows emissions and fuel consumption credits to be averaged, banked, or traded (5-year credit life). Manufacturers allowed to carry forward credit deficits for up to 3 model years. Interim incentives for advanced technologies, recognition of innovative (off-cycle) technologies not accounted for by the Phase 1 test procedures, and credits for certifying early.	Same as Phase 1, except no extra credits for advanced technologies or early certification.
Trailers hauled by tractors, except those qualified as logging, mining, stationary or heavy-haul		
Share of HD vehicle fuel consumption and GHG emissions	Trailers are modeled with combination tractors and their engines. Together, they account for approximately two-thirds of fuel use and GHG emissions in the medium and heavy duty truck sector.	
Form of the standard	Trailers were not regulated in Phase 1.	Gallons of fuel/1,000 ton payload mile (gal/1,000 ton-miles).
Example technology options available to help manufacturers meet standards		Low-rolling resistance tires, automatic tire inflation and pressure monitoring systems, trailer weight reduction, aerodynamic improvements such as side and rear fairings, gap closing devices, and undercarriage treatment.
Flexibilities		One year delay in implementation for small businesses, trailer manufacturers may use pre-approved devices to avoid testing, averaging program for manufacturers of dry and refrigerated box trailers beginning in 2027.
Classes 2b–8 chassis that are intended for vocational services[a]		
Share of HD vehicle fuel consumption and GHG emissions	Vocational vehicles account for approximately 20% of fuel use and GHG emissions in the medium and heavy duty truck sector categories.	
Form of the standard	Gallons of fuel/1,000 ton payload mile (gal/1,000 ton-miles).	

	Phase 1 Program	Phase 2 Program
Example technology options available to help manufacturers meet standards	Low-rolling resistance tires and engine improvements.	Further technology improvements and increased use of Phase 1 technologies, plus improved engines, transmissions and axles, powertrain optimization, weight reduction, hybrids, and workday idle reduction systems.
Flexibilities	ABT program that allows emissions and fuel consumption credits to be averaged, banked, or traded (5 year credit life). Manufacturers allowed to carry-forward credit deficits for up to 3 model years. Interim incentives for advanced technologies, recognition of innovative (off-cycle) technologies not accounted for by the Phase 1 test procedures, and credits for certifying early.	Same as Phase 1, except no advanced technology incentives. Chassis intended for emergency vehicles have Phase 2 standards based only on Phase 1 technologies, and may continue to certify using a simplified Phase 1-style GEM tool.
Classes 2b–3 complete pickup trucks and vans[b]		
Share of HD vehicle fuel consumption and GHG emissions	HD pickups and vans account for approximately 15% of fuel use and GHG emissions in the medium and heavy duty truck sector.	
Form of the standard	Target curves based on a "work factor" attribute that combines truck payload and towing capabilities, with an added adjustment for four-wheel drive vehicles. There are separate target curves for diesel-powered and gasoline-powered vehicles.	
Example technology options available to help manufacturers meet standards	Engine improvements, transmission improvements, aerodynamic drag improvements, low-rolling resistance tires, weight reduction, and improved accessories.	Further technology improvements and increased use of all Phase 1 technologies, plus engine stop-start, and powertrain hybridization (mild and strong).
Flexibilities	Two optional phase-in schedules; ABT program, which allows emissions and fuel consumption credits to be averaged, banked, or traded (5-year credit life). Manufacturers allowed to carry forward credit deficits for up to 3 model years. Interim incentives for advanced technologies, recognition of innovative (off-cycle) technologies not accounted for by the Phase 1 test procedures, and credits for certifying early.	ABT program the same as Phase 1. Adjustment factor of 1.25 for credits carried forward from Phase 1 to Phase 2 due to change in useful life. Cessation of advanced technology incentives in 2021 and continuation of off-cycle credits.

Notes:

[a] Vocational services include delivery vehicles, emergency vehicles, dump truck, tow trucks, cement mixer, refuse trucks, etc., except those qualified as off-highway vehicles. Because of sector diversity, vocational vehicle chassis are segmented into Light, Medium and Heavy Duty vehicle categories and for Phase 2 each of these segments are further subdivided using three duty cycles: regional, multi-purpose, and urban.

[b] Including all work vans and 15-passenger vans but excluding 12-passenger vans, which are subject to light-duty standards

GHG = greenhouse gas; ABT = averaging, banking, and trading; gal/100 bhp-hr = gallons per 100 brake horsepower-hour; gal/1,000 ton-miles = gallons of fuel/1,000 ton payload mile; GEM = Greenhouse Gas Emission Model.

1.3.2.2.1 HD Vehicle Engines

NHTSA and EPA are continuing the basic Phase 1 structure for the Phase 2 engine standards. There are separate standards and test cycles for tractor engines, vocational diesel engines, and vocational gasoline engines. However, Phase 2 uses a revised test cycle for tractor engines to better reflect actual in-use operation. For diesel engines, the agencies are increasing the stringency of engine standards. For gasoline engines, however, the agencies are not adopting more stringent engine standards. A complete discussion of the Final Action as it relates to HD vehicle engines is included in Section II of the Final Rule.

1.3.2.2.2 Classes 7–8 Combination Tractors

As explained in Section III of the Final Rule, NHTSA and EPA will largely continue the Phase 1 tractor program but are adding new, more stringent standards. The agencies project that the final Phase 2 tractor standards can be met through improvements in various tractor engine and vehicle technologies. The agencies enhanced the Greenhouse Gas Emission Model (GEM) vehicle simulation tool to recognize these technologies, as described in Section II.C of the Final Rule.

1.3.2.2.3 Classes 7–8 Trailers

Phase 2 includes fuel consumption and GHG emissions standards for manufacturers of new trailers that are used in combination with tractors. Trailers that are qualified as logging, mining, stationary, or heavy-haul are excluded. As described in Section IV of the Final Rule, there are aerodynamic and tire technologies available to manufacturers to accomplish these standards. For the most part, these technologies have already been introduced into the market to some extent through EPA's voluntary SmartWay program. However, adoption is still somewhat limited.

NHTSA's fuel consumption standards are voluntary beginning in MY 2018 and mandatory beginning in MY 2021, while EPA's GHG emissions standards are mandatory beginning in MY 2018. As described in Section XIV.D of the Final Rule and Chapter 12 of the Final Regulatory Impact Analysis (RIA), Phase 2 includes special provisions to minimize the impacts on small trailer manufacturers.

1.3.2.2.4 Classes 2b–8 Vocational Vehicles

Phase 2 revises the Phase 1 vocational vehicle program and imposes new standards. These standards also reflect further sub-categorization from Phase 1, with separate standards based on mode of operation: urban, regional, and multi-purpose. NHTSA and EPA are issuing alternative standards for emergency vehicles. Phase 2 also includes revisions to the compliance regime for vocational vehicles. These include the addition of an idle cycle that would be weighted along with the other drive cycles and revisions to the vehicle simulation tool to reflect specific improvements to the engine, transmission, and driveline. Section V of the Final Rule contains a complete discussion of the Final Action as it relates to Classes 2b–8 vocational vehicles.

1.3.2.2.5 HD Pickups and Vans (Classes 2b–3)

The agencies are issuing new Phase 2 fuel consumption and GHG emissions standards for HD pickups and vans that will be applied in largely the same manner as the Phase 1 standards. These standards are based on the extensive use of most known and proven technologies. These standards will commence in MY 2021. Section VI of the Final Rule contains a complete discussion of the Final Action as it relates to HD pickups and vans.

1.4 Cooperating Agencies

Under 40 Code of Federal Regulations (CFR) § 1501.6, a federal agency that has special expertise with respect to any environmental issue that should be addressed in the EIS may be a cooperating agency upon request of the lead agency. On May 12, 2014, NHTSA invited EPA, DOE, and the DOT's Federal Motor Carrier Safety Administration (FMCSA) to become cooperating agencies with NHTSA in the development of this EIS for the Phase 2 HD National Program. EPA has special expertise in the areas of climate change and air quality, DOE has special expertise in vehicle technologies that improve fuel efficiency, and FMCSA has special expertise in HD vehicles.[45]

In its invitation letters, NHTSA suggested that EPA, DOE, and FMCSA roles in the development of the EIS could include the following, as they relate to the agencies' areas of special expertise:

- Identifying the significant issues to be analyzed in the EIS from a fuel use, climate change, and air quality perspective for heavy-duty vehicles.
- Participating in the scoping process as appropriate and, in particular, assisting NHTSA to "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."[46]
- Providing information and expertise on manufacture, sale, operation, and maintenance, of heavy-duty vehicles.
- Providing information and expertise related to technologies for improving the fuel efficiency of heavy-duty vehicles.
- Providing technical assistance, information, and expertise for modeling environmental impacts related to manufacture and use of heavy-duty vehicles.
- Participating in coordination meetings, as appropriate.
- Reviewing and commenting on the Draft EIS and Final EIS prior to publication.

EPA and DOE accepted NHTSA's invitation and agreed to become cooperating agencies. Staff members from each of these agencies participated in technical discussions, provided technical assistance, and/or reviewed and commented on the Draft and Final EISs prior to publication

1.5 Public Review and Comment

NHTSA submitted to EPA a Draft EIS to disclose and analyze the potential environmental impacts of the agency's Proposed Action and reasonable alternative standards pursuant to CEQ NEPA implementing regulations, DOT Order 5610.1C, and NHTSA regulations. The Draft EIS was posted to the NHTSA EIS docket (Docket No. NHTSA-2014-0074) on June 19, 2015, and EPA published a Notice of Availability in the Federal Register on June 26, 2015.[47] The Draft EIS requested public input on the agency's environmental analysis by August 31, 2015; publication of the Notice of Availability in the Federal Register triggered the Draft EIS public comment period. On July 13, 2015, NHTSA and EPA published the

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[45] *See* Section 1.5 of the Medium- and Heavy-Duty Fuel Efficiency Improvement Program Final Environmental Impact Statement (NHTSA 2011) for additional discussion of EPA's and FMCSA's expertise.

[46] 40 CFR § 1501.7(a)(3).

[47] 80 FR 36803 (June 26, 2015).

Phase 2 NPRM,[48] and opened a 60-day comment period. The agencies invited the public to submit comments on the NPRM on or before September 11, 2015, by posting to either the NHTSA or EPA docket (NHTSA-2014-0132 or EPA-HQ-OAR-2014-0827). The comment periods for the NPRM and the Draft EIS were subsequently extended to October 1, 2015.[49]

Consistent with NEPA and its implementing regulations, NHTSA mailed a copy of the Draft EIS 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 expected to be interested in the NEPA analysis for the new Phase 2 HD vehicle fuel efficiency standards, including advocacy, industry, and other organizations.

NHTSA and EPA held joint public hearings on the Draft EIS and NPRM on August 6, 2015 in Chicago, Illinois, and on August 18, 2015 in Long Beach, California. NHTSA received 66 oral comments during the public hearing in Long Beach, California and 50 oral comments during the public hearing in Chicago, Illinois. The agency also received several hundred comments in the dockets for the Draft EIS and the NPRM. NHTSA reviewed the oral and written submissions for comments relevant to the EIS. Several commenters referenced or submitted studies, research, and other information supporting or in addition to their comments. NHTSA carefully reviewed these submissions to determine if they were appropriate for inclusion in this EIS.

As described in Chapter 9 of this EIS, comments that raised issues central to the rule or the rulemaking process will be addressed in the preamble to the Final Rule, the RIA, or associated documents in the public docket.

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

NHTSA is issuing this Final EIS concurrently with the Final Rule (Record of Decision), which states and explains NHTSA's decision and describes NHTSA's consideration of applicable environmental laws and policies.[50] NHTSA has determined that concurrent issuance of the Final EIS and Record of Decision is not precluded by statutory criteria[51] or practicability considerations. EPA will announce the availability of this Final EIS in the *Federal Register*.

[48] *See* Phase 2 NPRM, *supra* note 19.

[49] *See* Extension of Comment Period for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2, 80 FR 53756 (Sept. 8, 2015).

[50] 49 U.S.C. 304a (Pub. L. No. 114-94, 129 Stat. 1312, Section 1311(a)) and U.S. Department of Transportation *Final Guidance on MAP-21 Section 1319 Accelerated Decisionmaking in Environmental Reviews* (http://www.dot.gov/sites/dot.gov/files/docs/MAP-21_1319_Final_Guidance.pdf).

[51] 49 U.S.C. 304a(b)(1)-(2).

CHAPTER 2 FINAL ACTION AND ALTERNATIVES AND ANALYSIS METHODOLOGIES

2.1 Introduction

NEPA requires that, in the case of a major federal action, an agency must 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]

As explained in Chapter 1, NHTSA and EPA are issuing a second phase of standards to improve fuel efficiency for medium- and heavy-duty (HD) vehicles and reduce greenhouse gas (GHG) emissions, referred to as Phase 2 HD National Program standards. NHTSA's Final Action establishes Phase 2 HD standards that build on the Phase 1 fuel efficiency standards for HD engines and vehicles for model years (MYs) 2014–2018, in order to continue to increase HD fuel efficiency after 2018, in accordance with the Energy Policy and Conservation Act (EPCA), as amended by the Energy and Independence Security Act of 2007 (EISA). NHTSA developed the Final Action and alternatives in accordance with the EISA requirements discussed in Chapter 1, as well as relevant environmental and safety considerations. As with Phase 1, NHTSA's Phase 2 HD Fuel Efficiency Improvement Program rulemaking has been conducted in consultation with EPA and the U.S. Department of Energy (DOE).[4] Consistent with the Council on Environmental Quality (CEQ) NEPA implementing regulations, this EIS compares the Action and a reasonable range of alternatives to Alternative 1 (No Action Alternative), which assumes that NHTSA and EPA would not issue a new rule regarding HD vehicle fuel efficiency and GHG emissions standards.[5] 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 in order to demonstrate the impacts of the action alternatives.[6]

Under the No Action Alternative, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. Therefore, the fuel efficiency and GHG emissions standards for the final year of regulation for each segment under the Phase 1 program are assumed to continue indefinitely, and this serves as the basis for the No Action Alternative for the analysis of Phase 2 impacts. While the same technology penetrations are generally assumed in the Phase 2 No Action Alternative as anticipated

[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] *See* 49 U.S.C. § 32902(k)(2).

[5] 40 CFR § 1502.14(d).

[6] *See* 40 CFR §§ 1502.2(e), 1502.14(d). The Council on Environmental Quality (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 (1981).

under the Phase 1 fuel consumption and GHG standards, the values for No Action Alternative standards reported in this EIS are not directly comparable to values for the standards reported in the Phase 1 Final Rule and Final EIS because the agencies established several Phase 2 test-procedure and minor regulatory changes that affect the way that standards are measured.

- First, compliance with overall HD vehicle standards is determined using the agencies' Greenhouse Gas Emissions Model (GEM) to simulate overall vehicle fuel efficiency given a set of vehicle component inputs. However, the Phase 2 version of GEM will obtain higher (i.e., less favorable) carbon dioxide (CO_2) and fuel consumption values than the Phase 1 version of GEM because the Phase 2 drive cycles include road grade, which exists in the real-world, requiring the engine to operate at higher horsepower levels to maintain speed while climbing a hill.
- Second, to better reflect the aerodynamic performance of tractor-trailers, the agencies input the wind averaged coefficient of drag into Phase 2 GEM instead of the no-wind (zero yaw) value used in Phase 1.
- Third, the Phase 2 program includes a more realistic and improved simulation of the transmission in GEM, which could increase CO_2 and fuel consumption relative to Phase 1.
- Fourth, the agencies recalculated APU deployment in tractors based on the current level of automatic engine shutdown and idle reduction technologies used by tractor manufacturers to comply with the 2014 model year fuel consumption and CO_2 standards.
- Finally, the Phase 2 No Action Alternative vocational vehicle standards also cannot be directly compared to Phase 1 standards because the Phase 2 program establishes further segmentation of vocational vehicle standards by fuel type and duty cycle.

For presentation in this chapter, NHTSA has recalculated the Phase 1 standards for the No Action Alternative of each segment using the new test procedures and regulatory changes in order to allow the reader to better understand the stringency levels of the action alternatives. The numbers are for presentation purposes only and do not correspond to actual changes in the standards from Phase 1, even if the No Action Alternative had been selected.

This chapter describes the action alternatives examined in this EIS, explains the methodologies and assumptions applied in estimating environmental impacts, and summarizes environmental impacts reported in subsequent EIS chapters. Readers may consult the Final Rule and Regulatory Impact Analysis (RIA) documents for more detailed information on the individual alternatives, including the methodology by which they were developed, projected technologies, adoption rates, costs, etc. The remainder of this chapter is organized as follows:

- Section 2.2 describes the standards for HD engines, HD pickups and vans, vocational vehicles, tractors, and trailers under the No Action Alternative (Alternative 1), the Preferred Alternative (Alternative 3), and the other action alternatives (Alternatives 2, 4, and 5).
- Section 2.3 explains how direct and indirect impacts and cumulative impacts of each action alternative are measured against a No Action Alternative (Alternative 1), which assumes that neither NHTSA nor EPA would issue a rule regarding Phase 2 HD fuel consumption standards or GHG emissions standards.
- Section 2.4 summarizes environmental impacts reported in subsequent EIS chapters.

2.2 Phase 2 Standards and Alternatives

The HD vehicle sector is often subdivided by gross vehicle weight rating (GVWR), which is a measure of the combined curb (empty) weight and cargo carrying capacity of the truck. Table 2.2-1 outlines the GVWR classifications commonly used for a variety of purposes by businesses and federal agencies.

Table 2.2-1. HD Vehicle Weight Classification

Class	2b	3	4	5	6	7	8
Gross Vehicle Weight Rating (GVWR) (pounds)	8,501–10,000	10,001–14,000	14,001–16,000	16,001–19,500	19,501–26,000	26,001–33,000	> 33,000

In the framework of these GVWR classifications, HD vehicles refer to Classes 2b–8 and the engines that power those vehicles. HD vehicles often vary widely in configuration (i.e., are composed of different vehicle parts combined in different ways). In setting Phase 1 HD vehicle standards, EPA and NHTSA divided the industry into discrete categories—HD pickups and vans, vocational vehicles, and combination tractors—based on the relative homogeneity among vehicles within each category. The agencies established separate fuel consumption standards for each of these HD vehicle categories. The agencies also decided that setting separate standards for the engines that power combination tractors and vocational vehicles, as well as complete vehicle fuel efficiency standards for each category of HD vehicles best met the purpose and need for that action. NHTSA believes that this same general structure of setting engine standards for vocational vehicles and combination tractors; separate HD vehicle fuel consumption standards for HD pickups and vans, vocational vehicles, and combination tractors; and adding, for the first time, fuel consumption standards for certain trailers used in combination with the Classes 7–8 tractors best meets the purpose and need for Phase 2 standards, and allows for the achievement of "maximum feasible improvement" in HD vehicle fuel efficiency.

HD pickups and vans (Classes 2b–3) are used chiefly as work trucks and vans, shuttle vans, and personal transportation vehicles. Other HD vehicles are used for carrying cargo and/or performing specialized tasks. "Vocational" vehicles, which span Classes 2b–8, vary widely in size, including smaller and larger van trucks, utility "bucket" trucks, tank trucks, refuse trucks, urban and over-the-road buses, fire trucks, flat-bed trucks, and dump trucks, among others. Classes 7–8 combination tractor-trailers (some equipped with sleeper cabs and some not) are primarily used for freight transportation.

The variability of the HD vehicle fleet is reflected in different fuel consumption standards for HD engines and different types of HD vehicles (specified as gallons of fuel per horsepower-hour [gal/100 bhp-hr] for engines, gal/100 miles for HD pickups and vans, and gallons of fuel per 1,000 ton payload mile [gal/1,000 ton-miles] for tractor-trailers and vocational vehicles). Fuel consumption standards, including engine standards, are based on specific drive cycles chosen based on the typical expected use of each vehicle. The drive cycle used in compliance testing has significant consequences for the technology that will be employed to achieve a standard, as well as the ability of the technology to achieve real-world reductions in fuel consumption. Therefore, compliance testing for fuel consumption standards varies to reflect the anticipated drive cycles in different segments of the HD vehicle market.

The Final Rule specifies standards and compliance testing requirements for HD engines, HD pickups and vans, vocational vehicles, tractors, and trailers. In this EIS, Alternative 3, the Preferred Alternative, refers to the same standards and testing requirements specified as the final standards in the Final Rule.[7]

[7] The analysis in this EIS specifically corresponds to "Method A" results in the Phase 2 Final Rule.

Alternative 2 is less stringent than the Preferred Alternative (i.e., would require less fuel efficiency improvement than Alternative 3), and Alternative 5 is the most stringent action alternative examined in this analysis. In the Proposed Rule and Draft EIS, Alternative 3 and Alternative 4 were designed to achieve similar fuel efficiency and GHG emissions levels in the long term, but with Alternative 4 being accelerated in its implementation timeline. In practice, this meant that Alternative 4 was more stringent than Alternative 3 in the Draft EIS. In response to comments received on the Proposed Rule and Draft EIS, the agencies revised Alternative 3 (the Preferred Alternative). As a result, the Final EIS standards for the Preferred Alternative are more stringent overall than the Draft EIS proposed standards for the Preferred Alternative. Standards for Alternative 4 in this Final EIS are the same as the Alternative 4 standards in the Draft EIS in order to provide a benchmark for comparison of the revised Preferred Alternative. Now, the Preferred Alternative is more stringent than Alternative 4 in this Final EIS for some vehicle categories. For a full discussion of the development of the final standards and alternatives, as well as their assumptions and stringency levels, consult the Final Rule and RIA. Those discussions are incorporated by reference herein.

The remainder of this section is organized into five subsections that describe the alternative standards examined by NHTSA and EPA for different segments of the HD vehicle market: HD engines, Classes 7–8 tractors, trailers, Classes 2b–8 vocational vehicles, and Classes 2b–3 HD pickups and vans. These five subsections detail the performance standards for different HD vehicle market segment under the No Action Alternative and each of the action alternatives.

2.2.1 HD Engines for Vocational Vehicles and Tractors

The Phase 1 program set engine performance standards and specified engine test procedures for Classes 2b–8 vocational vehicles and tractors (HD pickups and vans are regulated as complete vehicles in Phase 1, as described in Section 2.2.5). HD engine manufacturers are responsible for ensuring that each engine meets the applicable vehicle class engine performance standard when tested in accordance with the specified engine test procedure.

For the most part, the Phase 2 engine standards are a continuation of the Phase 1 program, but with more stringent standards for diesel (compression-ignition) engines, and important changes related to the test procedures and compliance provisions. Engine manufacturers can improve engine performance by applying combinations of fuel efficiency improvement technologies to the engine.

The Phase 2 diesel engine test procedure relies on two separate engine test cycles. The first is the Heavy-duty Federal Test Procedure (HD FTP) that includes transient operation typified by frequent accelerations and decelerations, similar to urban or suburban driving. The second is the Supplemental Engine Test (SET), which includes 13 steady-state test points, similar to highway cruise operation and other nominally steady-state operation. The gasoline (spark-ignition) engine test procedure relies on a single engine test cycle: a gasoline version of HD FTP. The agencies have not changed the gasoline engine test procedures or introduced new, more stringent standards for gasoline vocational engines, as discussed below. The specific engine performance standards examined vary with the intended engine application by vehicle class and the type of fuel used, as shown below in Table 2.2.1-1.

Table 2.2.1-1. HD Engine Regulatory Subcategories

Engine Category	Intended Application
Light Heavy-Duty (LHD) Diesel	Classes 2b–5 vehicles (8,501 through 19,500 pounds GVWR)
Medium Heavy-Duty (MHD) Diesel	Classes 6–7 vehicles (19,501 through 33,000 pounds GVWR)
Heavy Heavy-Duty (HHD) Diesel	Class 8 vehicles (33,001 pounds and greater GVWR)
Gasoline	Primarily for vehicles less than 14,000 pounds, including almost 50% of HD pickups and vans, and less than 10% of vocational vehicles.

Notes:
GVWR = gross vehicle weight rating; HD = heavy duty

2.2.1.1 Alternative 1 – No Action HD Engines for Vocational Vehicles and Tractors

Under Alternative 1, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. As a result, Phase 1 HD engine standards and test procedures would remain in effect indefinitely at their MY 2017 levels until amended by a future rulemaking action. Table 2.2.1-2 shows the MY 2017 Phase 1 standards for diesel engines used in Classes 7–8 tractors (recalculated as described in Section 2.1), which would remain in effect in MY 2018 and beyond under the Phase 2 No Action Alternative.

Table 2.2.1-2. Alternative 1 – No Action HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2017 and Later	CO_2 (g/bhp-hr)	482	455
	Fuel Consumption (gallon/100 bhp-hr)	4.7315	4.4714

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HHD = heavy heavy-duty; MHD = medium heavy-duty; SET = supplemental engine test

Table 2.2.1-3 shows MY 2017 Phase 1 standards for diesel engines used in Classes 2b–8 vocational vehicles (recalculated as described in Section 2.1), which would remain in effect in MY 2018 and beyond under the Phase 2 No Action Alternative.

Table 2.2.1-3. Alternative 1 – No Action HD Vocational Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2017 and Later	CO_2 (g/bhp-hr)	576	558	525
	Fuel Consumption (gallon/100 bhp-hr)	5.6606	5.4797	5.1579

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HD FTP = heavy-duty Federal Test Procedure; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

The Phase 1 rule also set a fuel consumption standard of 7.05 gallon/100 bhp-hr and CO_2 standard of 627 grams per brake horsepower-hour (g/bhp-hr) for MY 2016 and beyond for gasoline engines used in Classes 2b–8 vocational vehicles. This gasoline engine standard would apply under the Phase 2 No Action Alternative and under all of the Phase 2 action alternatives. The number of gasoline (spark-ignited) vocational vehicles sold is small, and these vehicles commonly share most of the same technology as equivalent complete pickups or vans, including the powertrain. The resulting market structure leads manufacturers of HD gasoline engines to have little market incentive to develop separate technology for vocational engines that are engine-certified, and engine technologies that are used in engine-certified vocational engines are also projected to be used on complete HD pickups and vans. Therefore, the agencies are continuing the Phase 1 standard for spark-ignited gasoline engines used in vocational vehicles, given the relatively small improvement projected with new standards, and the likelihood that most or all of this improvement would be achieved as a result of the complete pickup and van standards and the vocational vehicle-based standards.

Fuel consumption and emissions standards for engines used in Classes 7–8 tractors do not cover gasoline (or LHD diesel) engines, as those are not used in Classes 7–8 tractors. Therefore, the action alternative standards for HD engines for vocational vehicles and tractors, discussed below, focus on diesel engine standards, because the small number of gasoline engines used in vocational vehicles and tractors would be subject to the same standards under the No Action and action alternatives.

2.2.1.2 Alternative 2 HD Engines for Vocational Vehicles and Tractors

Under Alternative 2, diesel engines to be installed in Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.1-4.

Table 2.2.1-4. Alternative 2 HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	476	450
	Fuel Consumption (gallon/100 bhp-hr)	4.6748	4.4178
2024 and Later	CO_2 (g/bhp-hr)	464	439
	Fuel Consumption (gallon/100 bhp-hr)	4.5568	4.3097

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HHD = heavy heavy-duty; MHD = medium heavy-duty; SET = supplemental engine test

Table 2.2.1-5 presents the Alternative 2 fuel consumption and emissions standards for diesel engines fitted into vocational vehicles.

Table 2.2.1-5. Alternative 2 HD Vocational Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	570	551	519
	Fuel Consumption (gallon/100 bhp-hr)	5.5955	5.4167	5.0986
2024 and Later	CO_2 (g/bhp-hr)	558	541	509
	Fuel Consumption (gallon/100 bhp-hr)	5.4810	5.3131	4.9970

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HD FTP = heavy-duty Federal Test Procedure; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.1.3 Alternative 3 – Preferred HD Engines for Vocational Vehicles and Tractors

For diesel engines to be installed in Classes 7–8 tractors, the agencies are issuing the Alternative 3 (Preferred Alternative) standards shown in Table 2.2.1-6.

Table 2.2.1-6. Alternative 3 – Preferred HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	473	447
	Fuel Consumption (gallon/100 bhp-hr)	4.6464	4.3910
2024–2026	CO_2 (g/bhp-hr)	461	436
	Fuel Consumption (gallon/100 bhp-hr)	4.5285	4.2829
2027 and Later	CO_2 (g/bhp-hr)	457	432
	Fuel Consumption (gallon/100 bhp-hr)	4.4892	4.2436

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HHD = heavy heavy-duty; MHD = medium heavy-duty; SET = supplemental engine test

Table 2.2.1-7 presents the Alternative 3 (Preferred Alternative) fuel consumption and emissions standards for diesel engines to be installed in vocational vehicles.

Table 2.2.1-7. Alternative 3 – Preferred HD Vocational Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	563	545	513
	Fuel Consumption (gallon/100 bhp-hr)	5.5305	5.3536	5.0393
2024–2026	CO_2 (g/bhp-hr)	555	538	506
	Fuel Consumption (gallon/100 bhp-hr)	5.4519	5.2849	4.9705
2027 and Later	CO_2 (g/bhp-hr)	552	535	503
	Fuel Consumption (gallon/100 bhp-hr)	5.4224	5.2554	4.9411

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HD FTP = heavy-duty Federal Test Procedure; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.1.4 Alternative 4 HD Engines for Vocational Vehicles and Tractors

Under Alternative 4, diesel engines to be installed in Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.1-8.

Table 2.2.1-8. Alternative 4 HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	470	444
	Fuel Consumption (gallon/100 bhp-hr)	4.6180	4.3641
2024 and Later	CO_2 (g/bhp-hr)	458	433
	Fuel Consumption (gallon/100 bhp-hr)	4.5001	4.2561

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HHD = heavy heavy-duty; MHD = medium heavy-duty; SET = supplemental engine test

Table 2.2.1-9 presents the Alternative 4 fuel consumption and emissions standards for diesel engines to be installed in vocational vehicles.

Table 2.2.1-9. Alternative 4 HD Vocational Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	560	542	510
	Fuel Consumption (gallon/100 bhp-hr)	5.4979	5.3221	5.0096
2024 and Later	CO_2 (g/bhp-hr)	552	535	503
	Fuel Consumption (gallon/100 bhp-hr)	5.4228	5.2567	4.9440

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HD FTP = heavy-duty Federal Test Procedure; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.1.5 Alternative 5 HD Engines for Vocational Vehicles and Tractors

Under Alternative 5, diesel engines to be installed in Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.1-10.

Table 2.2.1-10. Alternative 5 HD Tractor Diesel Engine Standards (over SET Cycle)

Model Years	Standard	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	467	442
	Fuel Consumption (gallon/100 bhp-hr)	4.5896	4.3373
2024 and Later	CO_2 (g/bhp-hr)	455	431
	Fuel Consumption (gallon/100 bhp-hr)	4.4718	4.2293

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HHD = heavy heavy-duty; MHD = medium heavy-duty; SET = supplemental engine test

Table 2.2.1-11 presents the Alternative 5 fuel consumption and emissions standards for diesel engines fitted into vocational vehicles.

Table 2.2.1-11. Alternative 5 HD Vocational Diesel Engine Standards (over HD FTP Cycle)

Model Years	Standard	LHD Diesel	MHD Diesel	HHD Diesel
2021–2023	CO_2 (g/bhp-hr)	556	539	507
	Fuel Consumption (gallon/100 bhp-hr)	5.4654	5.2906	4.9800
2024 and Later	CO_2 (g/bhp-hr)	549	532	501
	Fuel Consumption (gallon/100 bhp-hr)	5.3937	5.2285	4.9175

Notes:
CO_2 = carbon dioxide; g = grams; bhp-hr = brake horsepower-hour; HD FTP = heavy-duty Federal Test Procedure; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.2 Classes 7–8 Tractors

Combination tractors consume the largest fraction of fuel among the HD vehicle categories. Tractors also offer significant potential for fuel savings due to the high annual mileage and average vehicle speeds within this category as compared to annual mileage and average speeds or duty cycles of other HD vehicle categories. In addition to the engine standards described above, the Phase 2 standards require Classes 7–8 tractor manufacturers to meet an overall vehicle performance standard by making various non-engine fuel saving technology improvements (e.g., by using a combination of technologies such as improving aerodynamics, lowering tire rolling resistance, decreasing vehicle mass [weight], reducing fuel use at idle, improving efficiency of transmissions, or other technologies).

The alternative standards examined for Classes 7–8 tractors vary depending on whether it is a "day cab" or "sleeper cab" (sleeper cabs provide overnight accommodations for drivers). Tractors with sleeper cabs tend to have greater empty curb weight than tractors with day cabs due to the larger cab accommodations, and some technologies (e.g., extended idle reduction) are appropriate for tractors with sleeper cabs but less so for day cabs. Standards for Class 8 tractors with day cabs versus sleeper cabs also reflect different drive cycles. Day cab tractors have a larger percentage of their drive cycle weighted to transient (urban) driving and sleeper cab tractors have a larger percentage of their drive cycle weighted to a cruising speed of 65 miles per hour. Standards for Classes 7–8 tractors also vary with the height of the roof, designed to correspond to the height of the trailer, because roof height significantly affects aerodynamic drag, which is an important determinant of tractor fuel efficiency.

For Phase 2, the agencies are also setting standards for an additional subcategory within the tractor category for "heavy-haul" tractors designed to haul much heavier loads than conventional tractors. The typical tractor designed in the United States has a gross combined weight rating (GCWR) of approximately 80,000 pounds due to the effective weight limit on the Federal highway system, except in states with preexisting higher weight limits. The Phase 2 standards for heavy-haul tractors apply to tractors with a GCWR over 120,000 pounds. The agencies also recognize that certain technologies used to determine the stringency of Phase 2 tractor standards are less applicable to the heavy-haul tractors designed for the U.S. market. For example, heavy-haul tractors in the United States are not typically used in the same manner as long-haul tractors with extended highway driving, and therefore, will experience less benefit from aerodynamics. The agencies are setting standards for heavy-haul tractors that reflect individualized performance of technologies in heavy-haul applications.

Compliance with the overall vehicle standards for Classes 7–8 tractors will be determined using GEM to simulate overall vehicle fuel efficiency given a set of vehicle component inputs. Using this approach, the Classes 7–8 vehicle manufacturers will supply certain vehicle characteristics that would serve as GEM inputs. Thus, vehicle manufacturers could make any combination of improvements using non-engine technologies that they believe would best achieve the Classes 7–8 tractor overall fuel consumption standards.

2.2.2.1 Alternative 1 – No Action Classes 7–8 Tractors

Under Alternative 1, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. As a result, Phase 1 tractor standards and test procedures would remain in effect indefinitely at their MY 2017 levels until amended by a future rulemaking action. For ease of comparison with the Phase 2 final standards and alternatives, the Phase 1 standards were recalculated as described above in Section 2.1. Table 2.2.2-1 shows the recalculated MY 2017 and beyond Phase 1 standards for Classes 7–8 tractors.

Table 2.2.2-1. Alternative 1 – No Action Classes 7–8 Tractor Standards

2017 Model Year and Later CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	117.3	89.5	81.9	58.3
Mid Roof	125.8	94.9	88.3	
High Roof	126.2	95.2	85.7	
2017 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	11.52136	8.79117	8.04048	5.72246
Mid Roof	12.36225	9.32629	8.67438	
High Roof	12.39501	9.34813	8.41860	

Notes:
CO_2 = carbon dioxide

2.2.2.2 Alternative 2 Classes 7–8 Tractors

Under Alternative 2, Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.2-2.

Table 2.2.2-2. Alternative 2 Classes 7–8 Tractor Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	113.2	86.4	77.9	56.2
Mid Roof	121.4	91.6	84.0	
High Roof	121.8	91.8	81.5	
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	11.11811	8.48348	7.65052	5.52217
Mid Roof	11.92957	8.99987	8.25367	
High Roof	11.96118	9.02094	8.01030	
2024 Model Year and Later CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	108.3	82.7	75.6	54.5
Mid Roof	116.3	87.8	81.7	
High Roof	115.7	87.3	78.6	
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	10.64232	8.12570	7.42693	5.35315
Mid Roof	11.42076	8.62688	8.02765	
High Roof	11.36744	8.57357	7.72183	

Notes:
CO_2 = carbon dioxide

2.2.2.3 Alternative 3 – Preferred Classes 7–8 Tractors

The Alternative 3 (Preferred Alternative) fuel efficiency and emissions standards for Classes 7–8 tractors that the agencies are issuing are shown in Table 2.2.2-3.

Table 2.2.2-3. Alternative 3 – Preferred Classes 7–8 Tractor Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	105.5	80.5	72.3	52.4
Mid Roof	113.2	85.4	78	
High Roof	113.5	85.6	75.7	
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	10.36346	7.90766	7.10216	5.14735
Mid Roof	11.11984	8.389	7.66208	
High Roof	11.14931	8.40864	7.43615	
2024–2026 Model Year CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	99.8	76.2	68.0	50.2
Mid Roof	107.1	80.9	73.5	
High Roof	106.6	80.4	70.7	
2024–2026 Model Year Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	9.80354	7.48527	6.67976	4.93124
Mid Roof	10.52063	7.94695	7.22004	
High Roof	10.47151	7.89784	6.94499	
2027 Model Year and Later CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	96.2	73.4	64.1	48.3
Mid Roof	103.4	78.0	69.6	
High Roof	100.0	75.7	64.3	
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	9.44990	7.21022	6.29666	4.74460
Mid Roof	10.15717	7.66208	6.83694	
High Roof	9.82318	7.43615	6.31631	

Notes:
CO_2 = carbon dioxide

2.2.2.4 Alternative 4 Classes 7–8 Tractors

Under Alternative 4, Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.2-4.

Table 2.2.2-4. Alternative 4 Classes 7–8 Tractor Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	103.4	78.9	71.3	51.4
Mid Roof	110.9	83.7	76.9	
High Roof	111.2	83.9	74.7	
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	10.15723	7.75030	7.00407	5.04492
Mid Roof	10.89856	8.22206	7.55625	
High Roof	10.92744	8.24131	7.33344	
2024 Model Year and Later CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	97.8	74.7	66.9	49.2
Mid Roof	105.0	79.3	72.3	
High Roof	104.5	78.8	69.5	
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	9.60775	7.33578	6.57058	4.83276
Mid Roof	10.31052	7.78824	7.10203	
High Roof	10.26238	7.74011	6.83147	

Notes:
CO_2 = carbon dioxide

2.2.2.5 Alternative 5 Classes 7–8 Tractors

Under Alternative 5, Classes 7–8 tractors would be subject to the fuel efficiency and emissions standards shown in Table 2.2.2-5.

Table 2.2.2-5. Alternative 5 Classes 7–8 Tractor Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	95.8	73.1	64.4	47.6
Mid Roof	102.8	77.6	69.4	
High Roof	103.1	77.7	67.4	
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	9.41180	7.18151	6.32143	4.67468
Mid Roof	10.09872	7.61865	6.81980	
High Roof	10.12548	7.63648	6.61870	
2024 Model Year and Later CO_2 Grams per Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	90.1	68.8	60.5	45.3
Mid Roof	96.7	73.0	65.4	
High Roof	96.2	72.6	62.9	
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		**Sleeper Cab**	**Heavy-Haul**
	Class 7	**Class 8**	**Class 8**	**Class 8**
Low Roof	8.84891	6.75638	5.93992	4.45105
Mid Roof	9.49617	7.17310	6.42036	
High Roof	9.45183	7.12878	6.17577	

Notes:
CO_2 = carbon dioxide

2.2.3 Trailers

The Phase 2 Final Rule includes, for the first time, fuel consumption standards for new trailers that begin with a voluntary three year program, followed by a mandatory program phasing in over a period of 7 years. EPA's GHG emissions standards for new trailers are mandatory from the beginning. Although the agencies are issuing new fuel consumption and CO_2 standards for trailers separately from tractors, the numerical level of the trailer standards is in relation to "standard" reference tractors in recognition of their interrelatedness. In other words, the regulatory standards refer to the simulated fuel consumption and emissions of a standard tractor pulling the trailer being certified.

The trailer industry produces different trailer designs for different applications, and the final standards will apply (in one form or another) to most types of trailers. The most comprehensive requirements will apply to box trailers (also called box vans), including refrigerated and non-refrigerated (dry) vans. Box trailers are the largest trailer category with the highest annual vehicle miles traveled, which offers the greatest potential for fuel consumption and CO_2 reductions. For highway non-box trailers, the agencies are adopting design standards that are not predicated on aerodynamic improvements but rather require manufacturers of these trailers to adopt specific tire technologies (low rolling resistance tires and either tire pressure monitoring or automatic tire inflation systems).

Some box trailers have work-performing equipment either on the underside or on the rear of the trailer that would limit a manufacturer's ability to install aerodynamic technologies. Instead, these may be designated as partial-aero vans for their given subcategory. The partial-aero standards are based on adoption of tire technologies and a single aerodynamic device throughout the program. Further, box trailers that have work-performing equipment on the underside and rear of the trailer may be designated non-aero box vans. Non-aero box vans are a single subcategory, and the applicable standards will not require the use of aerodynamic devices, but could be met by adopting low rolling resistance tires and either tire pressure monitoring or automatic tire inflation systems.

The Final Rule includes more details on the specific standards that apply to different subcategories of trailers that are more granular than the categories described below. Further, NHTSA notes that differences in the numerical values of trailer standards among trailer subcategories under each alternative reflect differences in the tractor-trailer characteristics (e.g., length, weight, aerodynamic performance, number of axles and tires, and tractor type), as well as differences in the default payloads, in the vehicle simulation model used to develop the trailer standards. Therefore, lower values do not necessarily indicate more stringent standards.

2.2.3.1 Alternative 1 – No Action Trailers

Under Alternative 1, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. There were no trailer standards under the Phase 1 program, so the Phase 2 No Action Alternative for trailers reflects the performance levels (simulated fuel consumption and emissions of a standard tractor pulling the trailer) that the agencies expect box trailers would achieve in the absence of any federal fuel consumption or GHG standards. Table 2.2.3-1 shows the Alternative 1 standards for full-aero box trailers that reflect such performance levels.

Table 2.2.3-1. Alternative 1 – No Action HD Box Trailer Standards (Full-Aero)

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2017 and Later	CO_2 Grams per Ton-Mile	83.2	126.5	84.9	130.3
	Gallons per 1,000 Ton-Mile	8.17098	12.42459	8.34183	12.80140

Notes:
CO_2 = carbon dioxide

Table 2.2.3-2 shows the Alternative 1 fuel efficiency and emissions standards for partial-aero box trailers that reflect such performance levels.

Table 2.2.3-2. Alternative 1 – No Action HD Box Trailer Standards (Partial-Aero)

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2017 and Later	CO_2 Grams per Ton-Mile	86.1	128.6	87.9	132.3
	Gallons per 1,000 Ton-Mile	8.45775	12.62796	8.63459	13.00056

Notes:
CO_2 = carbon dioxide

2.2.3.2 Alternative 2 Trailers

Under Alternative 2, full-aero box trailers would be subject to the fuel efficiency and emissions standards shown in Table 2.2.3-3 (simulated fuel consumption and emissions of a standard tractor pulling the trailer). Alternative 2 trailer standards would apply to only 53-foot box trailers and could be achieved by using less advanced aerodynamic and tire technologies than would be required by other action alternatives.

Table 2.2.3-3. Alternative 2 – HD Box Trailer Standards (Full-Aero)

		Dry Van		Refrigerated Van	
Model Years	**Standard**	**Long**	**Short**	**Long**	**Short**
2018–2020	CO_2 Grams per Ton-Mile	82.4	126.1	84.1	129.9
	Gallons per 1,000 Ton-Mile (Voluntary)	8.09355	12.38349	8.26413	12.76041
2021–2023	CO_2 Grams per Ton-Mile	81.4	125.5	83.1	129.4
	Gallons per 1,000 Ton-Mile	7.99474	12.32787	8.16700	12.70657
2024 and Later	CO_2 Grams per Ton-Mile	80.2	123.5	82.0	127.4
	Gallons per 1,000 Ton-Mile	7.88020	12.13124	8.05372	12.51253

Notes:
CO_2 = carbon dioxide

Table 2.2.3-4 shows the Alternative 2 fuel efficiency and emissions standards for partial-aero box trailers.

Table 2.2.3-4. Alternative 2 – HD Box Trailer Standards (Partial-Aero)

		Dry Van		Refrigerated Van	
Model Years	**Standard**	**Long**	**Short**	**Long**	**Short**
2018–2020	CO_2 Grams per Ton-Mile	84.1	127.4	85.9	131.2
	Gallons per 1,000 Ton-Mile (Voluntary)	8.26141	12.51696	8.43494	12.89287
2021 and Later	CO_2 Grams per Ton-Mile	83.8	126.8	85.6	130.7
	Gallons per 1,000 Ton-Mile	8.23278	12.45711	8.40642	12.83979

Notes:
CO_2 = carbon dioxide

2.2.3.3 Alternative 3 – Preferred Trailers

Under Alternative 3, the Preferred Alternative and the standards being issued in the Final Rule, full-aero box trailers will be subject to the fuel efficiency and emissions standards shown in Table 2.2.3-5 (simulated fuel consumption and emissions of a standard tractor pulling the trailer).

Table 2.2.3-5. Alternative 3 – Preferred HD Box Trailer Standards (Full-Aero)

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	81.3	125.3	83.0	129.1
	Gallons per 1,000 Ton-Mile (Voluntary)	7.98625	12.30845	8.15324	12.68173
2021–2023	CO_2 Grams per Ton-Mile	78.9	123.7	80.6	127.5
	Gallons per 1,000 Ton-Mile	7.75049	12.15128	7.91749	12.52456
2024–2026	CO_2 Grams per Ton-Mile	77.2	120.9	78.9	124.7
	Gallons per 1,000 Ton-Mile	7.58350	11.87623	7.75049	12.24951
2027 and Later	CO_2 Grams per Ton-Mile	75.7	119.4	77.4	123.2
	Gallons per 1,000 Ton-Mile	7.43615	11.72888	7.60314	12.10216

Notes:
CO_2 = carbon dioxide

Under Alternative 3, the Preferred Alternative, partial-aero box trailers would be subject to the fuel efficiency and emissions standards shown in Table 2.2.3-6 (simulated fuel consumption and emissions of a standard tractor pulling the trailer).

Table 2.2.3-6. Alternative 3 – Preferred HD Box Trailer Standards (Partial-Aero)

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	81.3	125.4	83.0	129.1
	Gallons per 1,000 Ton-Mile (Voluntary)	7.98625	12.31827	8.15324	12.68173
2021 and Later	CO_2 Grams per Ton-Mile	80.6	123.7	82.3	127.5
	Gallons per 1,000 Ton-Mile	7.91749	12.15128	8.08448	12.52456

Notes:
CO_2 = carbon dioxide

As explained above, non-box trailers and non-aero box vans are subject only to design standards for specific tire technologies. Non-box trailer tires would need to achieve a coefficient of rolling resistance of 6.0 kg/ton in MY 2018 (voluntary in the NHTSA program through MY 2020) and 5.1 kg/ton for MY 2021 and later model years. These requirements apply only to flatbed, tank, and container chassis non-box trailers (all others are excluded). Non-aero box vans would need to achieve a coefficient of rolling resistance of 5.1 kg/ton in MY 2018 (voluntary in the NHTSA program through MY 2020) and 4.7 kg/ton for MY 2021 and later model years. In addition, non-box trailer and non-aero box van manufacturers would need to install tire pressure monitoring or automatic tire inflation systems (voluntary beginning in MY 2018 and mandatory beginning MY 2021).

2.2.3.4 Alternative 4 Trailers

Under Alternative 4, full-aero box trailers would be subject to the fuel efficiency and emissions standards shown in Table 2.2.3-7 (simulated fuel consumption and emissions of a standard tractor pulling the trailer).

Table 2.2.3-7. Alternative 4 HD Box Trailer Standards (Full-Aero)

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	81.1	125.1	82.8	128.9
	Gallons per 1,000 Ton-Mile (*Voluntary*)	7.96706	12.28794	8.13340	12.66023
2021–2023	CO_2 Grams per Ton-Mile	78.5	123.2	80.1	127.0
	Gallons per 1,000 Ton-Mile	7.70680	12.10302	7.87286	12.47482
2024 and Later	CO_2 Grams per Ton-Mile	76.8	120.3	78.4	124.1
	Gallons per 1,000 Ton-Mile	7.54014	11.81671	7.70618	12.18811

Notes:
CO_2 = carbon dioxide

Table 2.2.3-8 shows the Alternative 4 fuel efficiency and emissions standards for partial-aero box trailers.

Table 2.2.3-8. Alternative 4 HD Box Trailer Standards (Partial-Aero)

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	80.8	124.8	82.5	128.5
	Gallons per 1,000 Ton-Mile (*Voluntary*)	7.93703	12.26397	8.10285	12.62403
2021 and Later	CO_2 Grams per Ton-Mile	80.0	122.8	81.7	126.6
	Gallons per 1,000 Ton-Mile	7.86109	12.06770	8.02689	12.43841

Notes:
CO_2 = carbon dioxide

2.2.3.5 Alternative 5 Trailers

Under Alternative 5, full-aero box trailers would be subject to the fuel efficiency and emissions standards shown in Table 2.2.3-9 (simulated fuel consumption and emissions of a standard tractor pulling the trailer).

Table 2.2.3-9. Alternative 5 HD Box Trailer Standards (Full-Aero)

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018–2020	CO_2 Grams per Ton-Mile	79.7	124.3	81.4	128.1
	Gallons per 1,000 Ton-Mile (*Voluntary*)	7.83348	12.21382	7.99536	12.58251
2021–2023	CO_2 Grams per Ton-Mile	75.4	121.4	77.0	125.2
	Gallons per 1,000 Ton-Mile	7.40274	11.92859	7.56225	12.29503
2024 and Later	CO_2 Grams per Ton-Mile	74.2	117.9	75.8	121.7
	Gallons per 1,000 Ton-Mile	7.28972	11.58600	7.45024	11.95016

Notes:
CO_2 = carbon dioxide

Table 2.2.3-10 shows the Alternative 5 fuel efficiency and emissions standards for partial-aero box trailers.

Table 2.2.3-10. Alternative 5 HD Box Trailer Standards (Partial-Aero)

Model Years	Standard	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
2018-2020	CO_2 Grams per Ton-Mile	77.3	122.8	78.9	126.4
	Gallons per 1,000 Ton-Mile (*Voluntary*)	7.59449	12.06770	7.75217	12.41547
2021 and Later	CO_2 Grams per Ton-Mile	76.0	119.8	77.6	123.5
	Gallons per 1,000 Ton-Mile	7.46860	11.76561	7.62612	12.12704

Notes:
CO_2 = carbon dioxide; HD = heavy duty

2.2.4 Classes 2–8 Vocational Vehicles

Fuel consumption standards for vocational vehicles vary by vehicle class (Classes 2b–5, Classes 6–7, and Class 8), ignition type and engine fuel (spark-ignited [SI] gasoline and combustion-ignited [CI] diesel), and duty cycle: Regional, Multi-Purpose, and Urban.[8] The three duty cycles have different weightings for two idle cycles plus the same driving cycles as for tractors and trailers: highway cruise cycles and ARB Transient cycle. Compliance with vocational vehicle standards will be determined by GEM simulation of vehicle fuel efficiency given a set of vehicle component inputs. Thus, vehicle manufacturers could make any combination of improvements that they believe would best achieve the vocational vehicle standards.

2.2.4.1 Alternative 1 – No Action Classes 2–8 Vocational Vehicles

Under Alternative 1, neither NHTSA nor EPA would issue a Phase 2 rule regarding HD fuel efficiency or GHG emissions. As a result, Phase 1 vocational vehicle standards and test procedures would remain in effect indefinitely at their MY 2017 levels until amended by a future rulemaking action. For ease of comparison with the Phase 2 final standards and alternatives, the Phase 1 standards were recalculated to reflect revised test procedures and the new subcategories (i.e., duty cycles) described above. Table 2.2.4-1 shows the Alternative 1 recalculated MY 2017 and beyond Phase 1 standards (the Phase 2 No Action Alternative) for Classes 2–8 diesel (CI) vocational vehicles.

Table 2.2.4-1. Alternative 1 – No Action Diesel (CI) Vocational Vehicle Standards

CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	459	322	335
Multi-Purpose	404	288	284
Regional	337	254	223
Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	45.0907	31.6119	32.9221
Multi-Purpose	39.6671	28.3012	27.8983
Regional	33.0736	24.9904	21.9124

Notes:
CO_2 = carbon dioxide; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

[8] The Draft EIS included standards under each alternative for spark-ignited gasoline Class 8 vocational vehicles. However, for the reasons explained in Section V of the Final Rule, based upon public comments on the NPRM, those have been removed from the Final EIS.

Table 2.2.4-2 shows the Alternative 1 recalculated MY 2017 and beyond Phase 1 standards for gasoline (SI) vocational vehicles.

Table 2.2.4-2. Alternative 1 – No Action Gasoline (SI) Vocational Vehicle Standards

CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	499	357
Multi-Purpose	441	319
Regional	363	284
Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	56.1584	40.1259
Multi-Purpose	49.5802	35.8442
Regional	40.8092	31.9294

Notes:
CO_2 = carbon dioxide; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.4.2 Alternative 2 Classes 2–8 Vocational Vehicles

Under Alternative 2, Classes 2–8 diesel (CI) vocational vehicles would be subject to the fuel efficiency and emissions standards shown in Table 2.2.4-3.

Table 2.2.4-3. Alternative 2 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	441	309	322
Multi-Purpose	388	277	273
Regional	323	244	214
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	43.3187	30.3411	31.6217
Multi-Purpose	38.1082	27.1634	26.7963
Regional	31.7738	23.9858	21.0469
2024 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	405	285	298
Multi-Purpose	362	258.8	254
Regional	312	233	204
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	39.8179	28.0062	29.2264
Multi-Purpose	35.5774	25.4226	24.9922
Regional	30.6132	22.8390	20.0351

Notes:
CO_2 = carbon dioxide; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

Table 2.2.4-4 shows the Alternative 2 fuel efficiency and emissions standards for gasoline (SI) vocational vehicles.

Table 2.2.4-4. Alternative 2 Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	479	342
Multi-Purpose	423	306
Regional	348	272
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	53.9514	38.5128
Multi-Purpose	47.6317	34.4033
Regional	39.2054	30.6459
Model Year and Later CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	455	326
Multi-Purpose	405	294
Regional	341	264
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	51.1791	36.6978
Multi-Purpose	45.6111	33.0280
Regional	38.3843	29.7134

Notes:
CO_2 = carbon dioxide; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.4.3 Alternative 3 – Preferred Classes 2–8 Vocational Vehicles

Table 2.2.4-5 shows the Alternative 3 (Preferred Alternative) fuel efficiency and emissions standards for CI diesel vocational vehicles that are being issued in the Final Rule.

Table 2.2.4-5. Alternative 3 – Preferred Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	424	296	308
Multi-Purpose	373	265	261
Regional	311	234	205
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	41.6503	29.0766	30.2554
Multi-Purpose	36.6405	26.0314	25.6385
Regional	30.5501	22.9862	20.1375
2024–2026 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	385	271	283
Multi-Purpose	344	246	242
Regional	296	221	194
2024–2026 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	37.8193	26.6208	27.7996
Multi-Purpose	33.7917	24.1650	23.7721
Regional	29.0766	21.7092	19.0570

2027 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	MHD (Classes 6–7)	HHD (Class 8)
Urban	367	258	269
Multi-Purpose	330	235	230
Regional	291	218	189
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	MHD (Classes 6–7)	HHD (Class 8)
Urban	36.0511	25.3438	26.4244
Multi-Purpose	32.4165	23.0845	22.5933
Regional	28.5855	21.4145	18.5658

Notes:
CO_2 = carbon dioxide; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

Table 2.2.4-6 shows the Alternative 3 (Preferred Alternative) fuel efficiency and emissions standards for SI gasoline vocational vehicles that are being issued in the Final Rule.

Table 2.2.4-6. Alternative 3 – Preferred Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	MHD (Classes 6–7)
Urban	461	328
Multi-Purpose	407	293
Regional	335	261
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	MHD (Classes 6–7)
Urban	51.8735	36.9078
Multi-Purpose	45.7972	32.9695
Regional	37.6955	29.3687
2024–2026 Model Year CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	MHD (Classes 6–7)
Urban	432	310
Multi-Purpose	385	279
Regional	324	251
2024–2026 Model Year Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	MHD (Classes 6–7)
Urban	48.6103	34.8824
Multi-Purpose	43.3217	31.3942
Regional	36.4577	28.2435
2027 Model Year and Later CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	MHD (Classes 6–7)
Urban	413	297
Multi-Purpose	372	268
Regional	319	247
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile		
	LHD (2b–5)	MHD (Classes 6–7)
Urban	46.4724	33.4196
Multi-Purpose	41.8589	30.1564
Regional	35.8951	27.7934

Notes:
CO_2 = carbon dioxide; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.4.4 Alternative 4 Classes 2–8 Vocational Vehicles

Under Alternative 4, Classes 2–8 diesel (CI) vocational vehicles would be subject to the fuel efficiency and emissions standards shown in Table 2.2.4-7.

Table 2.2.4-7. Alternative 4 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	428	298	309
Multi-Purpose	377	267	262
Regional	314	236	206
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	42.0877	29.2947	30.3640
Multi-Purpose	37.0253	26.2267	25.7306
Regional	30.8709	23.1586	20.2098
2024 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	380	268	279
Multi-Purpose	340	243	239
Regional	292	219	191
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	37.3538	26.3261	27.3983
Multi-Purpose	33.3758	23.8975	23.4290
Regional	28.7187	21.4689	18.7819

Notes:
CO_2 = carbon dioxide; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

Table 2.2.4-8 shows the Alternative 4 fuel efficiency and emissions standards for gasoline (SI) vocational vehicles.

Table 2.2.4-8. Alternative 4 Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	466	330
Multi-Purpose	411	295
Regional	339	263
2021–-2023 Model Year Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	52.4182	37.1847
Multi-Purpose	46.2781	33.2168
Regional	38.0913	29.5890
2024 Model Year and Later CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	427	307
Multi-Purpose	380	276
Regional	320	248

2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	48.0120	34.4962
Multi-Purpose	42.7885	31.0466
Regional	36.0090	27.9308

Notes:
CO_2 = carbon dioxide; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.4.5 Alternative 5 Classes 2–8 Vocational Vehicles

Under Alternative 5, Classes 2–8 diesel (CI) vocational vehicles would be subject to the fuel efficiency and emissions standards shown in Table 2.2.4-9.

Table 2.2.4-9. Alternative 5 Diesel (CI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	404	280	291
Multi-Purpose	355	251	247
Regional	296	222	194
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	39.6573	27.5529	28.6192
Multi-Purpose	34.8872	24.6673	24.2520
Regional	29.0882	21.7817	19.0485
2024 Model Year and Later CO_2 Grams per Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	359	252	262
Multi-Purpose	321	228.93	224.2
Regional	276	206	180
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile			
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**	**HHD (Class 8)**
Urban	35.2826	24.7736	25.7582
Multi-Purpose	31.5252	22.4882	22.0264
Regional	27.1263	20.2028	17.6576

Notes:
CO_2 = carbon dioxide; HHD = heavy heavy-duty; LHD = light heavy-duty; MHD = medium heavy-duty

Table 2.2.4-10 shows the Alternative 5 fuel efficiency and emissions standards for gasoline (SI) vocational vehicles.

Table 2.2.4-10. Alternative 5 Gasoline (SI) Vocational Vehicle Standards

2021–2023 Model Year CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	439	311
Multi-Purpose	388	278
Regional	319	247
2021–2023 Model Year Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	49.3913	34.9737
Multi-Purpose	43.6058	31.2418
Regional	35.8917	27.8297
2024 Model Year and Later CO_2 Grams per Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	403	288
Multi-Purpose	359	260
Regional	302	234
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile		
	LHD (Classes 2b–5)	**MHD (Classes 6–7)**
Urban	45.3499	32.4619
Multi-Purpose	40.4160	29.2157
Regional	34.0124	26.2837

Notes:
CO_2 = carbon dioxide; LHD = light heavy-duty; MHD = medium heavy-duty

2.2.5 Classes 2b–3 Pickups and Vans

For HD pickups and vans, vehicle testing will be conducted on chassis dynamometers using the drive cycles from the EPA FTP (or ‘‘city’’ test) and Highway Fuel Economy Test (HFET or ‘‘highway’’ test). The FTP and HFET results are weighted by 55 percent and 45 percent, respectively, and then harmonically averaged to calculate a combined cycle result. The 55/45 cycle weightings are the same as for the light-duty CAFE program, as NHTSA and EPA believe the real-world driving patterns for HD pickups and vans are similar to those of light-duty trucks except that HD pickups and vans are typically operated at higher loads than light-duty trucks. Compliance with fuel consumption standards for HD pickups and vans will continue to be determined through a fleet averaging process similar to the process used in determining passenger car and light truck compliance with CAFE standards.

The fuel consumption standards for HD pickups and vans are based on a “work factor” attribute that combines vehicle payload capacity and vehicle towing capacity, in pounds, with an additional fixed adjustment for four-wheel drive (4wd) vehicles. Fuel consumption targets would be determined for each vehicle with a unique work factor. These targets would then be production-weighted and summed to derive a manufacturer’s annual fleet average standards.

HD pickup and van standards vary in stringency across action alternatives, but all of the standards are based on a functional relationship between fuel economy and GHG emissions to a vehicle’s work factor, as described above. The No Action Alternative assumes Phase 1 HD pickup and van standards and test procedures would remain in effect indefinitely at their MY 2018 or MY 2019 levels (depending upon the implementation schedule chosen by manufacturers, as described in the Phase 1 Final Rule) until amended by a future rulemaking action. The action alternatives considered represent different rates of annual increase in fuel efficiency stringency, and Alternatives 2, 4, and 5 would only increase stringency through 2025, as shown in Table 2.2.5-1.

Table 2.2.5-1. Action Alternatives Examined for Phase 2 HD Pickup and Van Standards

Work-based Target Increases	Alternative 2	Alternative 3 – Preferred	Alternative 4	Alternative 5
Annual Stringency Increase	2.0%/year	2.5%/year	3.5%/year	4.0%/year
Stringency Increase Through	MY 2025	MY 2027	MY 2025	MY 2025
Total Stringency Increase	9.6%	15.6%	15.6%	17.9%

Notes:
MY = model year

Figures 2.2.5-1 and 2.2.5-2 illustrate the functional relationship between the work factor for HD pickups and vans and the corresponding fuel consumption targets under the Phase 2 Preferred Alternative for HD pickups and vans, specified in gal/100 miles (specific formulas for calculating work factors for HD pickups and vans under the action alternatives are presented in Section VI of the Final Rule).
Figure 2.2.5-1 shows that fuel consumption target standards for HD diesel pickups and vans for MY 2027 would be approximately 3.7 to 5.0 gal/100 miles, depending on the calculated work factor.
Figure 2.2.5-2 shows that the fuel consumption target standards for HD gasoline pickups and vans for MY 2027 would be approximately 4.4 to 6.1 gal/100 miles, depending on the calculated work factor.

Figure 2.2.5-1. Alternative 3 – Preferred Phase 2 HD Fuel Consumption and CO_2 Standards for Diesel HD Pickups and Vans

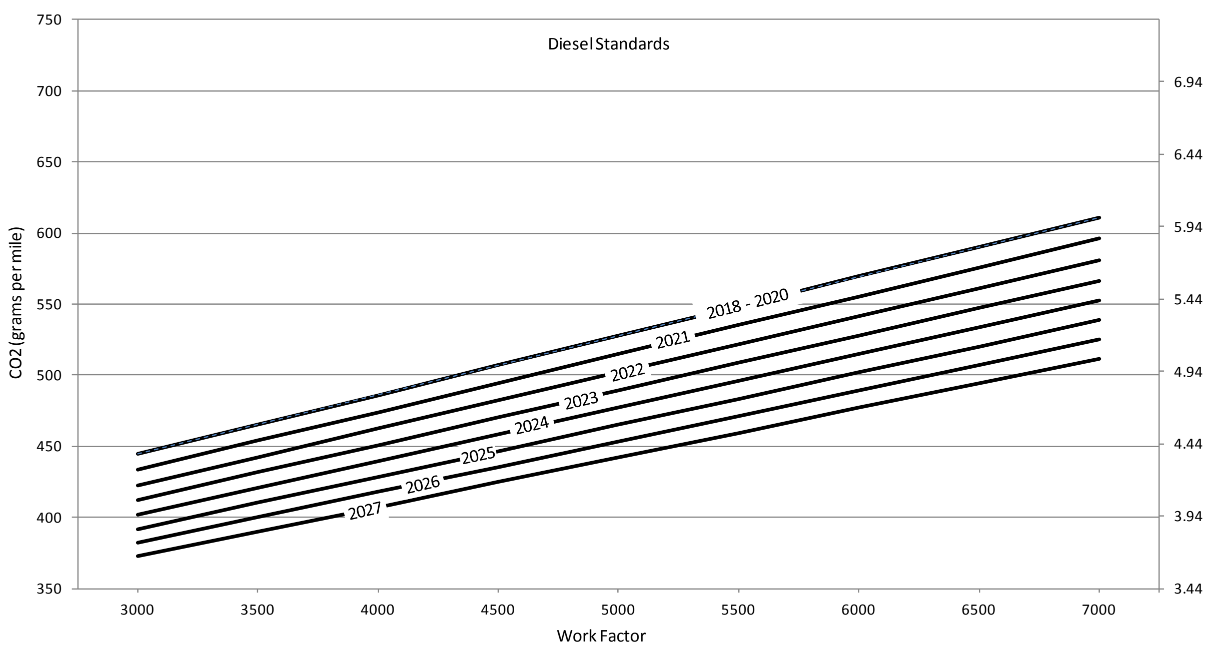
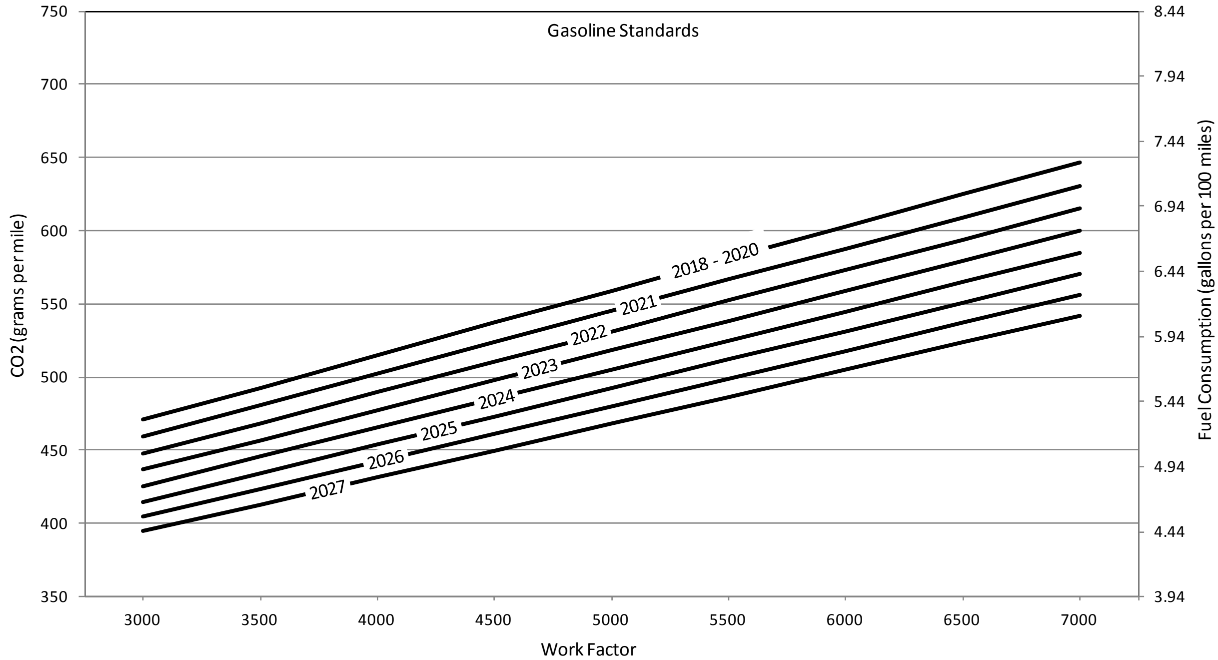


Figure 2.2.5-2. Alternative 3 – Preferred Phase 2 HD Fuel Consumption and CO_2 Standards for Gasoline HD Pickups and Vans



2.3 Direct and Indirect and Cumulative Impacts Analysis Methodologies

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."[9] 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."[10]

To derive the impacts of the action alternatives reported throughout this document, NHTSA compares the action alternatives to the No Action Alternative. The action alternatives in the direct and indirect impacts analysis and the cumulative impacts analysis are the same, but the No Action Alternative under each analysis reflects different assumptions to distinguish between direct and indirect impacts versus cumulative impacts.

The analysis of direct and indirect impacts compares action alternatives with a No Action Alternative that generally reflects a small forecast improvement in the average fuel efficiency of new HD vehicles after 2018 due to market-based incentives for improving fuel efficiency. In this way, the analysis of direct and indirect impacts isolates the portion of the fleet-wide fuel efficiency improvement

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[9] 40 CFR § 1508.8.

[10] 40 CFR § 1508.7.

attributable directly and indirectly to the Final Rule, and not attributable to reasonably foreseeable future actions by manufacturers after 2018 to improve new HD vehicle fuel efficiency even in the absence of new regulatory requirements.

The analysis of cumulative impacts compares action alternatives with a No Action Alternative that generally reflects no forecast improvement in the average fuel efficiency of new HD vehicles after 2018. As a result, the difference between the environmental impacts of the action alternatives and the cumulative impacts baseline reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 (i.e., reasonably foreseeable future changes in HD vehicle fuel efficiency) and the direct and indirect impacts of the Phase 2 standards associated with each action alternative. Therefore, this analysis reflects the cumulative impacts of reasonably foreseeable improvements in fuel efficiency after 2018 due to market-based incentives in addition to the direct and indirect impacts of the Phase 2 HD standards associated with each action alternative.

The No Action Alternative CO_2 emissions and fuel efficiency standards described in Section 2.2 reflect the performance levels forecast under the cumulative impacts No Action Alternative. For more information on how the agencies developed the baselines for analysis, readers may consult the Final Rule and RIA.

2.3.1 Resource Areas Affected and Types of Emissions

The major resource areas affected by the Final Action and alternatives are energy, air quality, and climate. Chapter 3 describes the affected environment for energy and energy impacts under each alternative. Chapters 4 and 5 describe the affected environments and impacts for air quality and climate change, respectively.

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.[11] Downstream emissions from tractor-trailers and vocational vehicles were estimated using a revised version of EPA’s Motor Vehicle Emission Simulator (MOVES2014) model (EPA 2015a). Downstream emissions from Classes 2b–3 vehicles were estimated using the most recent version of NHTSA’s CAFE Compliance and Effects Modeling System (the Volpe HD model).

Upstream emissions are those associated with crude-petroleum extraction and transportation, and with the refining, storage, and distribution of transportation fuels. NHTSA estimated both domestic and international upstream emissions of CO_2, and only domestic upstream emissions of criteria air pollutants and airborne toxics. To estimate Classes 2b–3 upstream emissions changes resulting from decreased downstream fuel consumption, the analysis uses the Volpe HD model, which incorporates emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (developed by the U.S. Department of Energy Argonne National Laboratory). The Volpe HD model uses the decreased volumes of the fuels along with the emissions factors from GREET for the various fuel production and transport processes to estimate the net changes in upstream emissions as a result of fuel consumption changes. To estimate Classes 4–8 upstream emissions, the analysis uses a

[11] NHTSA’s authority under EISA does not extend to regulating HFCs, which are released to the atmosphere through air-conditioning system leakage and are not directly related to fuel efficiency.

spreadsheet model developed by EPA that uses an identical methodology based on GREET emissions factors. Chapters 4 and 5 discuss modeling issues related specifically to the air quality and climate change analyses, respectively.

2.3.1.1 Downstream Emissions

Most downstream emissions are exhaust (tailpipe) emissions. The basic method used to estimate tailpipe emissions entails multiplying the total miles driven by HD vehicles of each model year and age by their estimated emissions rates per vehicle-mile of each pollutant. These emissions rates differ by fuel type (e.g., gasoline and diesel) and by vehicle type and vehicle age.

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

- Activity expressed as vehicle miles traveled (VMT), and emissions factors expressed as grams per VMT
- Activity expressed as fuel consumption in gallons, and emissions 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 sulfur dioxide (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. Therefore, emissions factors for CO_2 and SO_2 are not constant in terms of grams emitted per VMT of a specific vehicle, because fuel efficiency—and, therefore, 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 emissions controls with which a vehicle is equipped.

2.3.1.2 Upstream Emissions

The agencies also estimated the impacts of the action alternatives on upstream emissions associated with petroleum extraction and transportation, and refining, storage, and distribution of transportation fuels. NHTSA and EPA project that the Final Action would lead to reductions in upstream emissions from fuel production and distribution, because the total amount of fuel used by HD vehicles would decline under the action alternatives compared to the No Action Alternative.

2.3.2 Energy Market Forecast Assumptions

This EIS uses projections of energy consumption and supply derived from the U.S. Energy Information Administration (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 2040 for consumption and supply by energy fuel source, sector, and geographic region. The model used to formulate EIA projections incorporates forecast market trends and all federal and state laws and regulations in force at the time of modeling (e.g., the Phase 1 HD standards and MY 2017–2025 CAFE standards). Potential legislation and laws under debate in Congress are not included. This EIS uses projections of energy consumption and supply based on the 2015 AEO Reference Case. The 2016 AEO was released too recently to be reflected in this analysis.

2.3.3 Modeling Software

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. In addition, EPA modified the GREET model to add emissions factors for air toxics acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde.

For the action alternatives in this EIS, NHTSA assumed that increased fuel efficiency affects upstream emissions by causing decreases in the volumes of gasoline and diesel produced and consumed. The agencies calculated the impacts of decreased fuel production on total emissions of each pollutant using the volumes of fuels estimated to be produced and consumed under each action alternative, together with emissions factors for individual phases of the fuel production and distribution process derived from GREET. The emissions 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 derive 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. Table 2.3.3-1 lists the software used for computer simulation modeling of the projected HD vehicle fleet and its upstream and downstream emissions for the EIS. The table documents for each software, the common abbreviation, full title, version used, inputs to the software model, and the outputs from the model used in the EIS analysis.

Table 2.3.3-1. Inventory of EIS Modeling Software

Model	Title	Model Inputs	Model Outputs Used in this Analysis
NEMS (AEO 2015)	DOE—National Energy Modeling System	▪ Default values for AEO 2015	▪ Projected fuel prices for all fuels
GREET Fuel-Cycle model, as updated	DOE—GHG and Regulated Emissions in Transportation	▪ Tractor-trailers and vocational vehicles: GREET 1.8c model. In some cases, the GREET values were modified or updated by the agencies to be consistent with EPA's National Emissions Inventory and emissions factors from MOVES 2014. ▪ Classes 2b–3 vehicles: GREET 2013 model	▪ Estimates of upstream emissions associated with production, transportation, and storage for gasoline, diesel, and E85
MOVES (2014)	EPA—Motor Vehicle Emissions Simulator	▪ Emissions data from in-use chassis testing; remote	▪ NOx, SOx, CO, VOCs, PM2.5, and toxic emissions factors

Model	Title	Model Inputs	Model Outputs Used in this Analysis
		sensing; state vehicle inspection and maintenance; and other programs	(tailpipe, refueling, brake and tire wear) for HD vehicles
Volpe (2015 Version)	Volpe—CAFE Model	▪ Characteristics of baseline vehicle fleet ▪ Availability, applicability, and incremental effectiveness and cost of fuel-saving technologies ▪ Vehicle survival and mileage accumulation patterns ▪ Fuel economy rebound effect ▪ Future fuel prices, social cost of carbon, and other economic factors ▪ Fuel characteristics and criteria pollutant emissions factors	▪ Costs associated with utilization of additional fuel-saving technologies ▪ Changes in travel demand, fuel consumption, fuel outlays, ▪ Technology utilization scenarios ▪ Estimated U.S. vehicle fleet criteria and toxic emissions (tons) for future years
SMOKE (Version 3.6)	MCNC—Sparse Matrix Operator Kernel Emissions	▪ Criteria pollutant emissions outputs from MOVES, Volpe, or other models ▪ Emissions data for sources other than light-duty vehicles, from EPA National Emissions Inventory	▪ Gridded, speciated, hourly emissions for input into CMAQ and other models
CMAQ (Version 5.0.2)	EPA—Community Multi-scale Air Quality model	▪ SMOKE outputs ▪ Meteorological data	▪ Estimates of criteria pollutant concentrations and acid deposition. CMAQ includes a meteorological modeling system, emissions models, and a chemistry-transport modeling system for simulation of the chemical transformation and fate
BenMAP-CE (Version 1.1)	EPA—Environmental Benefits Mapping and Analysis Program—Community Edition	▪ CMAQ outputs ▪ Population and population distribution data ▪ Concentration-response data for health outcomes ▪ Valuation data for monetization of health outcomes	▪ Health effects (number of mortality and morbidity outcomes) ▪ Monetized health effects

Model	Title	Model Inputs	Model Outputs Used in this Analysis
GCAM RCP Scenario Results	Joint Global Change Research Institute's Global Change Assessment Model's simulations of the Representative Concentration Pathway radiative forcing targets	▪ Regional population estimates ▪ Labor productivity growth ▪ Energy demand ▪ Agriculture, land cover, and land-use models ▪ Atmospheric gas concentrations	▪ GCAMReference, GCAM6.0, and RCP4.5 global GHG emissions scenarios (baselines)
MAGICC (6)	National Center for Atmospheric Research—Model for the Assessment of Greenhouse-gas Induced Climate Change	▪ Adjusted GCAMReference, GCAM6.0, and RCP4.5 climate scenarios to reflect lower projected emissions from the heavy-duty vehicle fleet in the United States from the action alternatives	▪ Projected global CO_2 concentrations, and global mean surface temperature, from 2018–2100

Notes:
NEMS = National Energy Modeling System; AEO = Annual Energy Outlook; DOE = U.S. Department of Energy; GREET = Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation; GHG = greenhouse gas; EPA = U.S. Environmental Protection Agency; MOVES = Motor Vehicle Emissions Simulator; E85 = blend of gasoline and ethanol containing 51 to 83 percent ethanol; NO_x = nitrogen oxides; SO_x = sulfur oxides; CO = carbon monoxide; VOCs = volatile organic compounds; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; GCAM = Global Change Assessment Model; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; CO_2 = carbon dioxide; RCP = Representative Concentration Pathway; CMAQ = Congestion Mitigation and Air Quality Improvement

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:[12]

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.

In this EIS, NHTSA uses this approach—acknowledging incomplete or unavailable information—to address areas for which the agency cannot develop a reasonably precise estimate of the potential environmental impacts of the Final Action and alternatives. For example, NHTSA recognizes that

[12] 40 CFR § 1502.22(b).

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 Final Rule, is incomplete. NHTSA relies on the Intergovernmental Panel on Climate Change (IPCC) 2007 Fifth Assessment Report (IPCC 2013b, IPCC 2014b) as a recent "summary of existing credible scientific evidence which is relevant to evaluating the reasonably foreseeable significant adverse impacts on the human environment."[13]

2.4 Comparison of Alternatives

The CEQ NEPA 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."[14] This section summarizes and compares the direct, indirect, and cumulative impacts of the Final Action and alternatives on energy resources, 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 Sections 5.5 through 5.6, Chapter 6, and Chapter 7 of this EIS, so they are not summarized here.

In the alternatives analyzed in this EIS, the projected growth in the number of HD vehicles in use throughout the United States and in the annual VMT by HD vehicles would result in increased fuel consumption that outpaces improvements in efficiency resulting from each action alternative over the next decade, but Alternative 3 (Preferred Alternative) and Alternatives 4 and 5 would result in a forecast decline in annual HD vehicle fuel use beginning in the early 2020s. Annual HD vehicle fuel consumption after 2040 would also be lower than in 2015 under the Preferred Alternative and Alternatives 4 and 5. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles. NHTSA estimates that the HD vehicle fuel efficiency standards will reduce fuel consumption and CO_2 emissions from the future levels that would otherwise occur in the absence of the Phase 2 HD Fuel Efficiency Improvement Program (i.e., fuel consumption and CO_2 emissions under the No Action Alternative).

2.4.1 Direct and Indirect Impacts

This section compares the direct and indirect impacts of the No Action Alternative and the four action alternatives on energy, air quality, and climate as presented in Sections 3.4.1, 4.2.1, and 5.4.1, respectively (s*ee* Table 2.4.1-1). Under NEPA, direct effects "are caused by the action and occur at the same time and place."[15] Indirect impacts are those that "are caused by the action and are later in time or farther removed in distance but are still reasonably foreseeable."[16]

For detailed discussions of the assumptions and methodologies used to estimate the results presented in this section, *see* Sections 2.3, 3.4.1 (energy), 4.1.2 (air quality), and 5.3 (climate). As explained in Section 2.3, the direct and indirect effects methodology compares the action alternatives with a No Action Alternative that reflects a small forecast increase in the average fuel efficiency of new HD vehicles in 2018 and beyond, due to market-based incentives for improving fuel efficiency. By including

[13] 40 CFR § 1502.22(b)(3).

[14] *See* 40 CFR § 1502.14.

[15] 40 CFR § 1508.8.

[16] 40 CFR § 1508.8.

these market-based improvements in the No Action Alternative, this analysis attempts to isolate the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the Final Rule, and not attributable to reasonably foreseeable future actions by manufacturers.

Table 2.4.1-1. Direct and Indirect Impacts[a]

		Alternative 1 – No Action	Alternative 2	Alternative 3 – Preferred	Alternative 4	Alternative 5
Energy	Total combined gas, NG, E85, and diesel fuel consumption by all U.S. HD vehicles for 2019–2050	1,843.6 billion DGE	1,757.6 billion DGE	1,612.4 billion DGE	1,643.3 billion DGE	1,556.4 billion DGE
	Total fuel savings by all U.S. HD vehicles compared to No Action Alternative for 2019–2050	--	85.9 billion DGE	231.2 billion DGE	200.3 billion DGE	287.1 billion DGE
Air Quality	Criteria air pollutant (CO, NO_X, PM2.5, SO_2, and VOCs) emissions reductions from 2018–2050 compared to No Action Alternative	--	Emissions of all criteria pollutants will decrease compared to the No Action Alternative, with the exception of CO in 2018.	Emissions of all criteria pollutants will decrease compared to the No Action Alternative, with the exception of CO in 2018. The reductions in emissions will be greater than the reductions under Alternative 2 for all criteria pollutants.	Emissions of all criteria pollutants will decrease compared to the No Action Alternative, with the exception of CO in 2018. The reductions in emissions will be greater than the reductions under Alternative 3 for all criteria pollutants, except PM2.5, SO_2, and VOCs in 2040 and 2050.	Emissions of all criteria pollutants will decrease compared to the No Action Alternative, with the exception of CO in 2018. The reductions in emissions will be greater than the reductions under Alternatives 2, 3, and 4 for all criteria pollutants.
	Toxic air pollutant (acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde) emissions reductions for 2018–2050 compared to No Action Alternative	--	Emissions of all toxic pollutants will decrease or remain constant compared to the No Action Alternative in all years, with the exception of slight increases in acrolein in 2040 and 2050 and 1,3-	Emissions of all toxic pollutants will decrease or remain constant compared to the No Action Alternative in all years. The decreases in emissions will be similar to or greater than those under	Emissions of all toxic pollutants will decrease or remain constant compared to the No Action Alternative in all years, with the exception of slight increases in acrolein and 1,3-butadiene in	Emissions of all toxic pollutants will decrease or remain constant compared to the No Action Alternative in all years, with the exception of slight increases in acrolein and 1,3-butadiene in

		Alternative 1 – No Action	Alternative 2	Alternative 3 – Preferred	Alternative 4	Alternative 5
			butadiene in 2025, 2040, and 2050.	Alternative 2. Acrolein and 1,3-butadiene emissions will change only slightly in all years.	2025, 2040, and 2050. The increases in acrolein and 1,3-butadiene will be similar to or greater than those under Alternative 2. The decreases in acetaldehyde and benzene will be similar to or less than those under Alternative 3, while the decreases in DPM and formaldehyde will be similar to or greater than those under Alternative 3.	2025, 2040, and 2050. The increases in acrolein and 1,3-butadiene will be similar to those under Alternative 4. The decreases in acetaldehyde will be greater than those under Alternative 4 but less than those under Alternative 3, while the decreases in benzene, DPM, and formaldehyde will be greater than those under both Alternatives 3 and 4.
Air Quality	Reductions in premature mortality cases and work-loss days in 2040 (values within ranges depend on assumptions used)	--	Premature mortality: reduced by 172 to 386 cases Work-loss days: reduced by 21,470 days	Premature mortality: reduced by 485 to 1,086 cases Work-loss days: reduced by 60,492 days	Premature mortality: reduced by 437 to 978 cases Work-loss days: reduced by 54,287 days	Premature mortality: reduced by 607 to 1,358 cases Work-loss days: reduced by 75,494 days
Air Quality	Range of monetized health benefits in 2040 compared to No Action Alternative under a 3% and 7% discount rate (values within ranges depend on assumptions used)	--	3%: $1,978 million to $4,411 million 7%: $1,769 million to $3,994 million	3%: $5,572 million to $12,424 million 7%: $4,984 million to $11,247 million	3%: $5,010 million to $11,186 million 7%: $4,483 million to $10,130 million	3%: $6,962 million to $15,536 million 7%: $6,229 million to $14,066 million
Clima te	Total GHG emissions by all U.S. HD vehicles for	67,500 $MMTCO_2$	63,600 $MMTCO_2$ (3,800 $MMTCO_2$ [6%] less than the No Action	56,500 $MMTCO_2$ (10,900 $MMTCO_2$ [16%] less than the No	58,400 $MMTCO_2$ (9,100 $MMTCO_2$ [13%] less than the No Action	54,500 $MMTCO_2$ (13,000 $MMTCO_2$ [19%] less than the No

		Alternative 1 – No Action	Alternative 2	Alternative 3 – Preferred	Alternative 4	Alternative 5
	2018–2100		Alternative)	Action Alternative)	Alternative)	Action Alternative)
	Atmospheric CO_2 concentrations in 2100	789.1 ppm	788.8 ppm (0.3 ppm less than the No Action Alternative)	788.2 ppm (1.0 ppm less than the No Action Alternative)	788.3 ppm (0.8 ppm less than the No Action Alternative)	788.0 ppm (1.1 ppm less than the No Action Alternative)
	Increase in global mean surface temperature by 2100	3.484°C	3.483°C (0.001°C less than the No Action Alternative)	3.480°C (0.004°C less than the No Action Alternative)	3.481°C (0.003°C less than the No Action Alternative)	3.480°C (0.004°C less than the No Action Alternative)
	Global sea-level rise by 2100	76.28 cm	76.26 cm (0.03 cm less than the No Action Alternative)	76.21 cm (0.07 cm less than the No Action Alternative)	76.22 cm (0.06 cm less than the No Action Alternative)	76.19 cm (0.09 cm less than the No Action Alternative)
	Global mean precipitation increase by 2100	5.85%	5.85% (0.00% less than the No Action Alternative)	5.85% (0.01% less than the No Action Alternative)	5.85% (0.01% less than the No Action Alternative)	5.85% (0.01% less than the No Action Alternative)

Notes:

[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.

NG = natural gas; E85 = blend of gasoline and ethanol containing 51 to 83 percent ethanol; DGE = diesel gallons equivalent; CO = carbon monoxide; NO_x = nitrogen oxides; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; SO_2 = sulfur dioxide; VOCs = volatile organic compounds; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters; HD = heavy-duty; GHG = greenhouse gas; CO_2 = carbon dioxide

2.4.2 Cumulative Impacts

This section compares the cumulative impacts of the No Action Alternative and the four action alternatives on energy, air quality, and climate as presented in Sections 3.4.2, 4.2.2, and 5.4.2, respectively (s*ee* Table 2.4.2-1). 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…or person undertakes such other actions."[17]

For detailed discussions of the assumptions and methodologies used to estimate the results presented in this section, *see* Sections 2.3, 3.4.2, 4.1.2, and 5.3. As explained in Section 2.3, the cumulative impacts methodology compares the action alternatives with a No Action Alternative that assumes no increase in the average fuel efficiency of new HD vehicles after 2018 (i.e., no increase beyond the 2014–2018 Phase 1 HD standards). In other words, the difference between the environmental impacts of the action alternatives and the cumulative impacts baseline reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 (i.e., reasonably foreseeable future changes in HD vehicle fuel efficiency) and the direct and indirect impacts of the Phase 2 standards associated with each action alternative.

[17] 40 CFR § 1508.7.

Table 2.4.2-1. Cumulative Impacts

		Alternative 1 – No Action	Alternative 2	Alternative 3 – Preferred	Alternative 4	Alternative 5
Energy	Total combined gas, NG, E85, and diesel fuel consumption by all U.S. HD vehicles for 2019–2050	1,865.9 billion DGE	1,757.6 billion DGE	1,612.4 billion DGE	1,643.3 billion DGE	1,556.4 billion DGE
Energy	Total fuel savings by all U.S. HD vehicles compared to No Action Alternative for 2019–2050	--	108.3 billion DGE	253.5 billion DGE	222.6 billion DGE	309.4 billion DGE
Air Quality	Criteria air pollutant (CO, NO_X, PM2.5, SO_2, and VOCs) emissions reductions for 2018–2050 compared to No Action Alternative	--	Emissions of all criteria pollutant will decrease in all years compared to the No Action Alternative, with the exception of CO in 2018.	Emissions of all criteria pollutants will decrease in all years compared to the No Action Alternative, with the exception of CO in 2018. The decreases in emissions will be greater than the decreases under Alternative 2.	Emissions of all criteria pollutants will decrease compared to the No Action Alternative, with the exception of CO in 2018. The reductions in emissions will be greater than the reductions under Alternative 3 for all criteria pollutants, except PM2.5, SO_2, and VOCs in 2040 and 2050.	Emissions of all criteria pollutants will decrease compared to the No Action Alternative, with the exception of CO in 2018. The reductions in emissions will be greater than the reductions under Alternatives 2, 3, and 4 for all criteria pollutants.
Air Quality	Toxic air pollutant (acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde) emissions reductions from 2018–2050 compared to No Action Alternative	--	Emissions of all toxic pollutants will decrease or remain constant compared to the No Action Alternative in all years, with the exception of slight increases in	Emissions of all toxic pollutants will decrease or remain constant compared to the No Action Alternative in all years. The decreases in emissions will be	Emissions of all toxic pollutants will decrease or remain constant compared to the No Action Alternative in all years, with the exception of slight increases in	Emissions of all toxic pollutants will decrease or remain constant compared to the No Action Alternative in all years, with the exception of slight increases in

		Alternative 1 – No Action	Alternative 2	Alternative 3 – Preferred	Alternative 4	Alternative 5
			acrolein in 2040 and 2050 and 1,3-butadiene in 2025, 2040, and 2050.	similar to or greater than those under Alternative 2. Acrolein and 1,3-butadiene emissions will change only slightly in all years.	acrolein and 1,3-butadiene in 2025, 2040, and 2050. The increases in acrolein and 1,3-butadiene will be similar to or greater than those under Alternative 2. The decreases in acetaldehyde and benzene will be similar to or less than those under Alternative 3, while the decreases in DPM and formaldehyde will be similar to or greater than those under Alternative 3.	acrolein and 1,3-butadiene in 2025, 2040, and 2050. The increases in acrolein and 1,3-butadiene will be similar to those under Alternative 4. The decreases in acetaldehyde will be greater than those under Alternative 4 but less than those under Alternative 3, while the decreases in benzene, DPM, and formaldehyde will be greater than those under both Alternative 3 and Alternative 4.
Air Quality	Reductions in premature mortality cases and work-loss days in 2035 (values within range depend on assumptions used)	--	Premature mortality: reduced by 228 to 511 cases Work-loss days: reduced by 28,452 days	Premature mortality: reduced by 541 to 1,211 cases Work-loss days: reduced by 67,474 days	Premature mortality: reduced by 493 to 1,104 cases Work-loss days: reduced by 61,269 days	Premature mortality: reduced by 663 to 1,484 cases Work-loss days: reduced by 82,476 days
	Range of monetized health benefits in 2035 compared to No Action Alternative under a 3% and 7% discount rate (values within range depend on assumptions used)	--	3%: $2,621 million to $5,843 million 7%: $2,345 million to $5,292 million	3%: $6,215 million to $13,856 million 7%: $5,559 million to $12,546 million	3%: $5,652 million to $12,618 million 7%: $5,058 million to $11,428 million	3%: $7,605 million to $16,968 million 7%: $6,804 million to $15,364 million

		Alternative 1 – No Action	Alternative 2	Alternative 3 – Preferred	Alternative 4	Alternative 5
Climate	Total GHG emissions by All U.S. HD vehicles from 2014–2100	68,600 $MMTCO_2$	63,600 $MMTCO_2$ (5,000 $MMTCO_2$ [7%] less than the No Action Alternative)	56,500 $MMTCO_2$ (12,100 $MMTCO_2$ [18%] less than the No Action Alternative)	58,400 $MMTCO_2$ (10,200 $MMTCO_2$ [15%] less than the No Action Alternative)	54,500 $MMTCO_2$ (14,200 $MMTCO_2$ [21%] less than the No Action Alternative)
	Atmospheric CO_2 concentrations in 2100	687.3 ppm	686.9 ppm (0.4 ppm less than the No Action Alternative)	686.3 ppm (1.0 ppm less than the No Action Alternative)	686.4 ppm (0.9 ppm less than the No Action Alternative)	686.1 ppm (1.2 ppm less than the No Action Alternative)
	Increase in global mean surface temperature by 2100	2.838°C	2.836°C (0.002 °C less than the No Action Alternative)	2.834°C (0.004 °C less than the No Action Alternative)	2.834°C (0.004°C less than the No Action Alternative)	2.833°C (0.005°C less than the No Action Alternative)
	Global sea-level rise by 2100	70.22 cm	70.19 cm (0.04 cm less than the No Action Alternative)	70.14 cm (0.09 cm less than the No Action Alternative)	70.15 cm (0.07 cm less than the No Action Alternative)	70.12 cm (0.10 cm less than the No Action Alternative)
	Global mean precipitation increase by 2100	4.77%	4.76% (0.00% less than the No Action Alternative)	4.76% (0.01% less than the No Action Alternative)	4.76% (0.01% less than the No Action Alternative)	4.76% (0.01% less than the No Action Alternative)

Notes:

NG = natural gas; E85 = blend of gasoline and ethanol containing 51 to 83 percent ethanol; DGE = diesel gallons equivalent; CO = carbon monoxide; NOx = nitrogen oxides; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; SO_2 = sulfur dioxide; VOCs = volatile organic compounds; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters; HD = heavy-duty; GHG = greenhouse gas; CO2 = carbon dioxide

CHAPTER 3 ENERGY

NHTSA's HD standards regulate HD fuel efficiency and, therefore, affect U.S. transportation 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 transportation fuel consumption will account for most U.S. net energy imports through 2040 (as explained below in this chapter), the United States has the potential to achieve large reductions in imported oil use and, consequently, in net energy imports during this time, by improving the fuel efficiency of HD vehicles. Reducing dependence on energy imports is a key component of President Obama's May 29, 2014, *All-of-the-Above Energy Strategy*, which also states that the development of HD Phase 2 standards "will lead to large savings in fuel, lower carbon dioxide (CO_2) emissions, and health benefits from reduced particulate matter and ozone" (White House 2014b).

The president's *All-of-the-Above Energy Strategy* documents how the combination of increased U.S. oil and natural gas production, more electricity generation from renewables such as wind and solar, and gains in energy efficiency have produced "substantial economic and energy security benefits." These benefits include a decline in U.S. net petroleum imports, reflecting a decline in crude oil imports, and an increase in refined petroleum product exports, thereby reducing the vulnerability of the United States to foreign oil supply disruptions while also reducing the overall U.S. trade deficit.

This chapter discusses past, present, and forecast U.S. energy production and consumption, and the percentage of net petroleum imports resulting from current HD vehicle fuel consumption trends. This chapter also compares this affected energy environment to energy impacts under the Final Action and alternatives. The chapter is organized as follows.

- Section 3.1, *Energy Intensity*, describes energy intensity and consumption and how trends in U.S. energy intensity relate to trends in the U.S. share of global energy consumption.
- Section 3.2, *Affected Environment*, 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 HD vehicle fuel use affects overall energy use.
- Section 3.3, *Heavy-Duty Vehicle Fuel Efficiency and U.S. Energy Security*, describes how improving the fuel efficiency of HD vehicles would affect U.S. energy security by reducing the overall U.S. trade deficit and the macroeconomic vulnerability of the United States to foreign oil supply disruptions.
- Section 3.4, *Environmental Consequences*, describes the energy impacts of the Final Action and alternatives, including direct and indirect (Section 3.4.1) and cumulative impacts (Section 3.4.2).

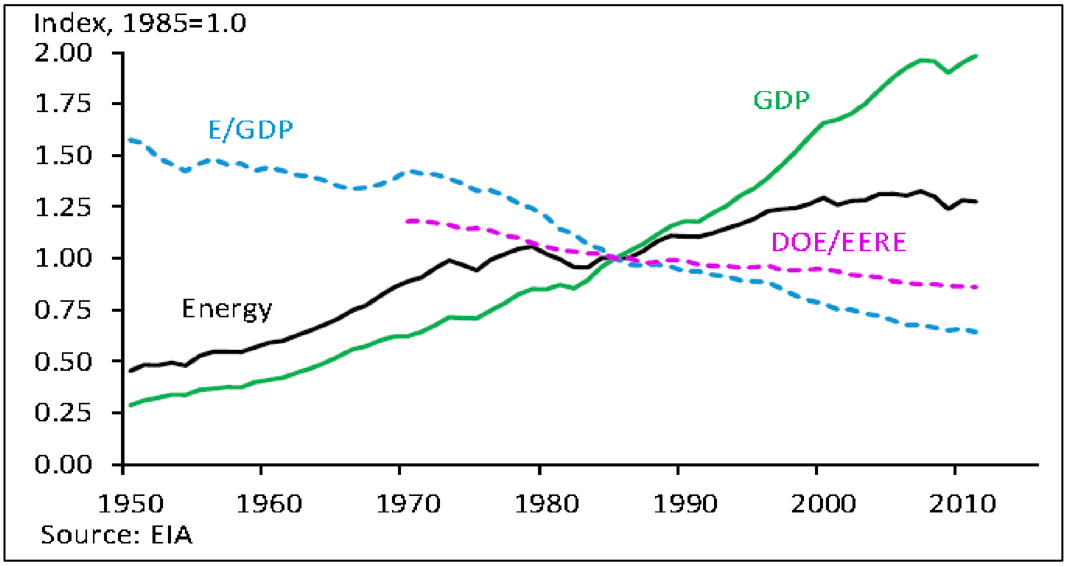
Sections 3.2 and 3.3 provide detailed projections for energy consumption and production through 2040 from the *Annual Energy Outlook* (AEO) 2015 (EIA 2015) and data reported in *All-of-the-Above Energy Strategy* from the AEO 2014 (EIA 2014a). The AEO 2015 forecasts reflect current enacted legislation and final regulations as of the end of October 2014, but do not reflect the impacts of the Final Action, which are discussed in Section 3.4.

Figures in this chapter from the *All-of-the-Above Energy Strategy* (White House 2014b) are based on the AEO 2014 forecast, and differences with the updated AEO 2015 forecasts are noted in the text.[1]

3.1 Energy Intensity

Energy intensity is often calculated as the sum of all energy supplied to an economy (in thousand British thermal units [Btu]) 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). This energy-GDP ratio (E/GDP) can decline due to improvements in energy efficiency and/or shifts from more to less energy-intensive sectors of the economy (e.g., an increasing percentage of GDP from the services sector and a decrease in the percentage of GDP from energy-intensive manufacturing). The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) has developed an economy-wide energy intensity index that estimates how the amount of energy needed to produce the same basket of goods has changed over time. Figure 3.1-1 shows that this DOE/EERE index fell by 14 percent from 1985 to 2011, as the E/GDP ratio fell by 36 percent, illustrating that the decline in energy use per dollar of GDP has come from improvements in energy efficiency and shifts in the composition of GDP.

Figure 3.1-1. U.S. Energy Intensity, 1950–2011



Source: White House 2014b.
GDP = gross domestic product; E/GDP = energy-GDP ratio; DOE = U.S. Department of Energy; EERE = Office of Energy Efficiency and Renewable Energy

Figure 3.1-1 also shows that the relationship between growth in GDP and total energy consumption has changed over the past 6 decades. From 1950 to 1970, GDP growth was associated with nearly parallel growth in energy consumption, with little change in energy intensity. From 1970 to 2000, the DOE/EERE

[1] The AEO 2015 is a shorter edition that includes a limited number of model updates, predominantly to reflect historical data updates and changes in legislation and regulation from October 2013 to October 2014. Under a new 2-year cycle, full and shorter editions of the AEO will be produced in alternating years. AEO 2016 was not released at the time this analysis was conducted.

and E/GDP measures of energy intensity both declined, but total energy consumption still increased as GDP growth more than offset improvements in energy efficiency and shifts in GDP composition that reduced energy intensity. From 2000 to 2011, the United States recorded substantial GDP growth with almost no increase in energy consumption due to reductions in energy intensity. The AEO 2015 forecasts ongoing declines in U.S. energy intensity, with average 2013–2040 GDP growth of 2.4 percent per year resulting in average annual energy consumption growth of just 0.3 percent (EIA 2015).

The decline in U.S. energy intensity, combined with rapid economic growth and increased energy use 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 2009, the U.S. share had fallen to 19.4 percent (EIA 2014b), and the 2016 International Energy Outlook forecasts that the U.S. share of global energy consumption will fall to 13.0 percent by 2040 (EIA 2014c).

3.2 Affected Environment

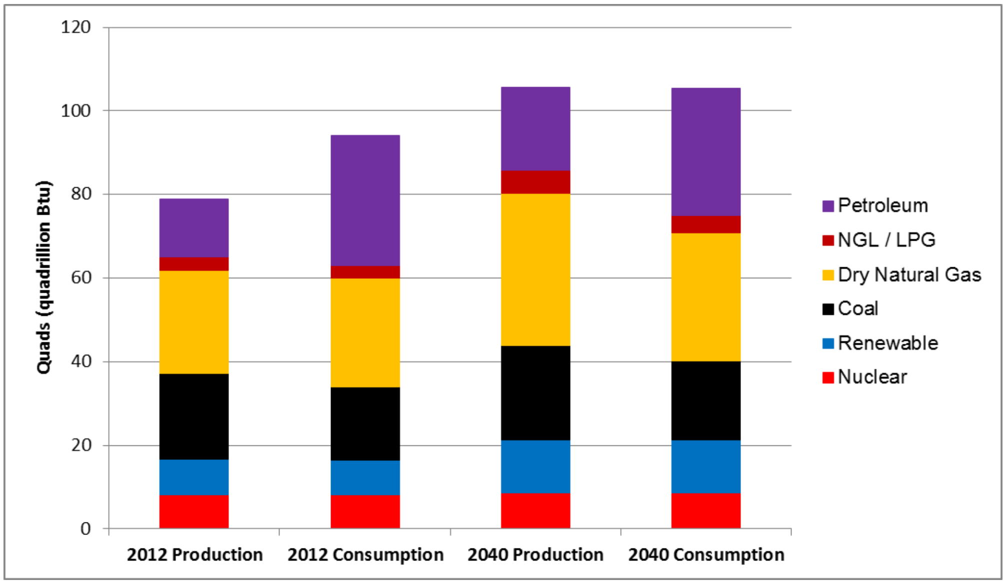
Although petroleum is overwhelmingly the primary source of energy for HD vehicles today, HD vehicles can use other fuels (e.g., natural gas), and the Final Action has the potential to reduce transportation petroleum demand and thereby affect the availability and use of fuels consumed by different economic sectors. Understanding how primary fuel markets are expected to evolve in the coming years also provides context for considering energy impacts of the Final Action. Therefore, 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.

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, coal, natural gas, crude oil (converted to petroleum products for consumption), and natural gas liquids (converted to liquefied petroleum gases for consumption). These five energy sources accounted for 91 percent of U.S. energy consumption in 2012. Hydropower, biomass, solar, wind, and other renewable energy accounted for 9 percent of U.S. energy consumption in 2012.

By 2040, the top five aforementioned energy sources are forecast to account for 88 percent of U.S. energy consumption, a reduction of 3 percent from their previous share, while the share of energy from renewable fuels is forecast to rise to 12 percent (EIA 2015). Forecast gains in U.S. oil and natural gas production, more electricity generation from renewables, and energy efficiency improvements are expected to significantly reduce the difference between U.S. energy production and consumption from 2012 through 2040, and eliminate U.S. reliance on net energy imports by 2040. Figure 3.2.1-1 illustrates this change in U.S. fuel consumption and production from 2012 to 2040 (not including the impacts of the Final Action).

Figure 3.2.1-1. U.S. Energy Production and Consumption by Source in 2012 and 2040



Source: EIA 2015
Btu = British thermal unit; NGL = natural gas liquid; LPG = liquefied petroleum gas

From 2012 to 2040, production and consumption of nuclear power is forecast to increase from 8.1 to 8.7 quadrillion Btu (quads), and production and consumption of renewable fuel is forecast to increase from approximately 8.5 quads in 2012 to 12.5 quads in 2040. The forecast growth in renewable energy includes an increase in hydropower production and consumption from 2.6 quads in 2012 to 2.8 quads in 2040, and increases in biomass energy (e.g., ethanol and other liquid fuel from crops, and grid-connected electricity from wood and other biomass) and other renewable energy (e.g., wind and solar), from approximately 5.9 quads in 2012 to 9.7 quads in 2040. Electric power generation accounts for 64 percent of forecast renewable fuel use in 2040, and the industrial sector accounts for another 20 percent. Because production and consumption are roughly equivalent for nuclear and renewable energy, there are essentially no net imports associated with these energy sources.[2] These fuels supplied 17.6 percent of U.S. energy consumption in 2012, and their share of consumption is forecast to increase to 20.2 percent by 2040.

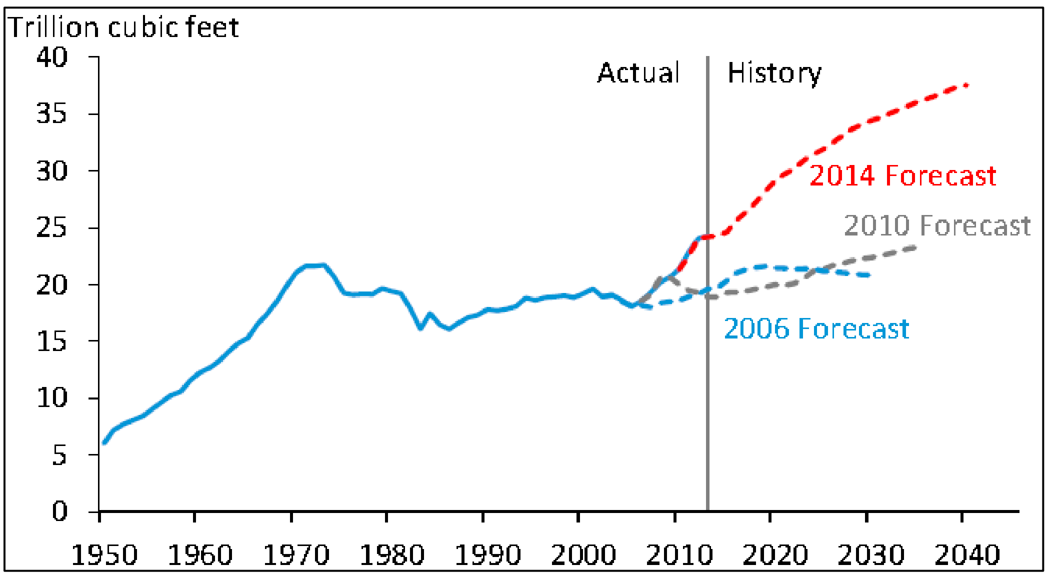
U.S. coal production is forecast to increase from 20.7 quads in 2012 to 22.7 quads in 2040, as coal consumption is expected to increase from 17.3 quads in 2012 to 19.0 quads in 2040. The United States is currently, and is expected to remain, a net exporter of coal energy through 2040, because the country is expected to continue to produce more coal than it consumes.

[2] 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, encompassing a nuclear fuel cycle that includes mining of uranium ore, conversion into uranium hexafluoride, and enrichment to increase the concentration of uranium-235 in uranium hexafluoride. U.S. nuclear plants in 2012 purchased 83 percent of their total uranium consumption from foreign suppliers, and 38 percent of the enriched uranium needed to fabricate fuel for U.S. reactors was supplied by foreign enrichers (EIA 2013).

U.S. production of dry natural gas (separated from natural gas liquids, discussed below) is forecast to increase from 24.6 quads in 2012 to 36.4 quads in 2040, while consumption of natural gas is expected to rise from 26.1 quads in 2012 to 30.5 quads in 2040, making the United States a net exporter of natural gas in 2017 through 2040. The forecast growth in natural gas is due to new production technologies that enabled an 11-fold increase in U.S. shale gas production from 2005 to 2011, with another 250 percent increase forecast for 2011 to 2040, more than offsetting declines in conventional natural gas production. The surge in shale gas production is why the AEO 2014 (EIA 2014a) forecast anticipated much higher natural gas production than had been foreseen in the AEO 2006 and 2010 forecasts (EIA 2006, 2010), as shown in Figure 3.2.1-2. (The AEO 2015 forecast for natural gas produced in 2040 shown in Figure 3.2.1-1 is 5 percent lower than the AEO 2014 forecast for 2040 reflected in Figure 3.2.1-2).

Production of natural gas liquid (NGL, a similar but heavier hydrocarbon compared to dry natural gas) is forecast to increase from 3.3 quads in 2012 to 5.5 quads in 2040. After extraction, natural gas liquid is separated from dry natural gas in processing plants and sold as ethane, propane, and other liquefied petroleum gases. Liquefied petroleum gas (LPG) consumption is forecast to increase from 3.0 quads in 2012 to 4.2 quads in 2040. Therefore, the increase in NGL production is expected to outpace the growth in LPG consumption, resulting in net exports for this subset of liquid fuels in 2012 through 2040.

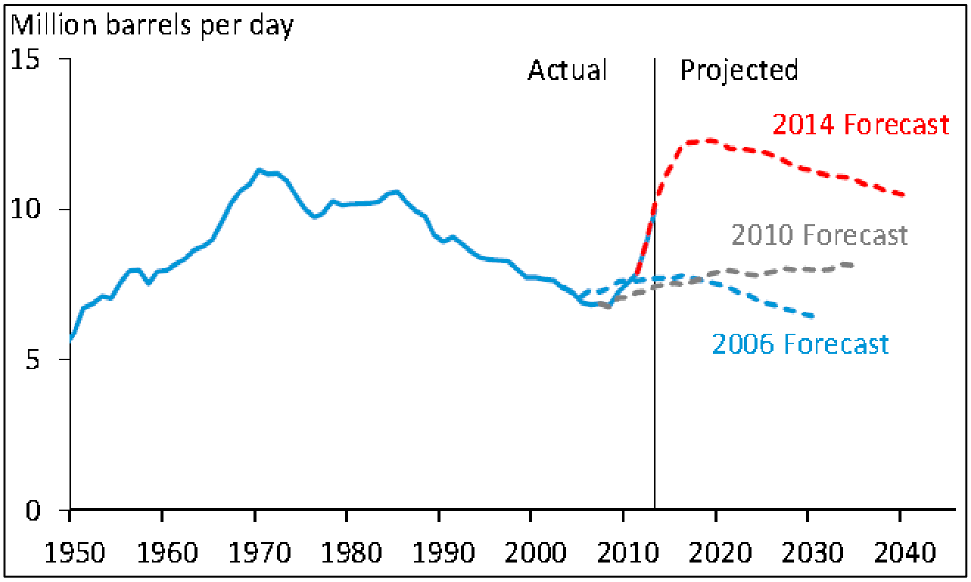
Figure 3.2.1-2. U.S. Natural Gas Production, 1950–2040



Source: White House 2014b.

U.S. production of crude oil is forecast to increase from 13.7 quads in 2012 to 19.9 quads in 2040. Crude oil is refined into petroleum products (including gasoline and diesel, but excluding non-petroleum liquid fuels, such as biofuels and LPG). U.S. consumption of petroleum is forecast to decline from 31.0 quads in 2012 to 30.5 quads in 2040. Therefore, U.S. net imports of petroleum are forecast to decline from 17.3 quads (3.1 billion barrels) in 2012 to 10.6 quads (1.9 billion barrels) in 2040. As in the case of natural gas production, advances in oil drilling technology resulted in a higher AEO 2014 (EIA 2014a) forecast for U.S. crude oil production than had been foreseen in the AEO 2006 and 2010 (EIA 2006, 2010) forecasts, as shown in Figure 3.2.1-3. (The AEO 2015 forecast for petroleum produced in 2040 shown in Figure 3.2.1-1 is 24 percent higher than the AEO 2014 forecast for 2040 reflected in Figure 3.2.1-2).

Figure 3.2.1-3. U.S. Petroleum Production, 1950–2040



Source: White House 2014b.

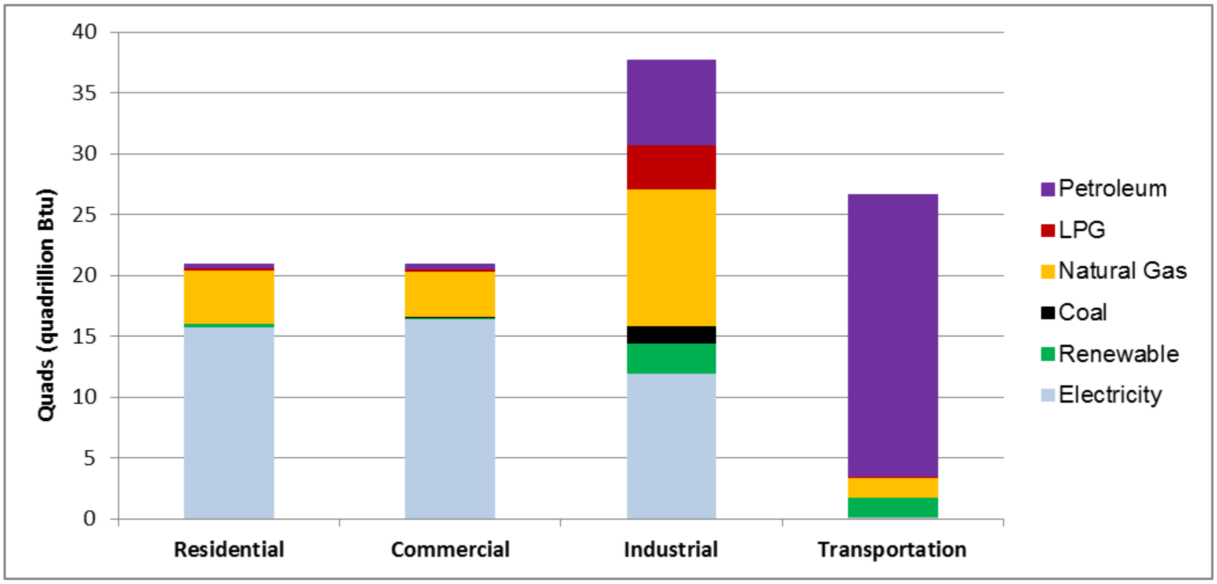
The primary fuel projections discussed above demonstrate that there are likely to be essentially no U.S. net imports of nuclear power and renewable energy, with U.S. net exports expected for coal, natural gas, and NGL from 2017 through 2040. U.S. petroleum net imports are also expected to decline to a level that is approximately equal to net exports of other primary fuels in 2040, resulting in a forecast of no net energy imports in 2040. As stated above, these forecasts do not include impacts from the Final Action, which would contribute to additional declines in petroleum consumption (discussed in Section 3.4) and associated reductions in petroleum net imports.

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 stationary (including industrial, residential, and commercial sectors) or mobile (i.e., transportation). Stationary and transportation sectors consume the primary fuels 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. Total primary energy consumption for electric power generation is forecast to increase from 38.3 quads in 2012 to 44.4 quads in 2040. In 2012, nuclear power supplied 21 percent of electric power generation source fuel, coal 41 percent, natural gas 24 percent, and renewable energy 12 percent. In 2040, nuclear power is expected to supply 20 percent of electric power generation source fuel, coal 39 percent, natural gas 22 percent, and renewable energy 18 percent. The petroleum share of electric power fuel supply is anticipated to decline from 0.6 percent in 2012 to just 0.4 percent in 2040.

Figure 3.2.2-1 illustrates sharply contrasting profiles for 2040 fuel consumption forecasts for stationary and transportation sectors, with stationary sectors 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. Forecast U.S. Energy Consumption by End-Use Sector and Source Fuel in 2040



Source: EIA 2015
Btu = British thermal unit; LPG = liquefied petroleum gas

3.2.2.1 Stationary-Sector Fuel Consumption

This section provides background information on stationary-sector fuel consumption, on which the Final Action would have a relatively small impact. Section 3.2.2.2 discusses transportation fuel consumption, on which the Final Action would be expected to have a larger impact.

Electricity (including energy losses during generation and transmission) and natural gas used on site (for heat, cooking, and hot water) are the principal forms of energy used by the residential and commercial sectors, accounting for 95 percent of 2012 energy use and 96 percent of forecast 2040 energy use in these two sectors. The industrial sector has more diverse energy consumption patterns, including coal, LPG, petroleum, and renewable energy, but electricity and natural gas still accounted for 57 percent of 2012 industrial sector energy use, and account for 55 percent of forecast 2040 energy use in this sector. New energy technologies to supply stationary energy to consumers must compete with an existing infrastructure that delivers electricity and natural gas reliably and at a relatively low cost, but energy efficiency improvements are expected to restrain total energy consumption growth in these sectors.

Residential-sector energy consumption is forecast to be little changed at 19.9 quads in 2012 and 20.9 quads in 2040, with this sector accounting for 21 percent of total U.S. energy consumption in 2012 and 20 percent of total forecast U.S. energy consumption in 2040. Residential consumption of liquid fuel (propane, kerosene, and distillate fuel oil) is expected to fall from 0.9 quads in 2012 to 0.5 quads in 2040. Residential consumption of renewable fuel (primarily wood for heating) and natural gas are expected to be essentially the same in 2012 and 2040, at 0.4 quads for renewable fuel and 4.3 quads for natural gas. Residential electricity use is expected to increase from 14.3 quads in 2012 to 15.8 quads in 2040.

Commercial-sector energy consumption is forecast to rise from 17.5 quads in 2012 to 20.9 quads in 2040, with this sector accounting for 19 percent of total U.S. energy consumption in 2012 and 20 percent of total forecast U.S. energy consumption in 2040. Commercial consumption of liquid fuel, renewable energy, and coal are all expected to be essentially the same in 2012 and 2040, at 0.6 quads for liquid fuel, 0.1 quads for renewable energy, and 0.05 quads for coal. Commercial natural gas use is expected to increase from 3.0 quads in 2012 to 3.7 quads in 2040, and commercial electricity use is forecast to increase from 13.8 quads in 2012 to 16.5 quads in 2040.

Industrial-sector energy consumption is projected to rise from 30.8 quads in 2012 to 37.7 quads in 2040, with this sector accounting for 33 percent of total U.S. energy consumption in 2012 and 36 percent of total forecast U.S. energy consumption in 2040. Industrial-sector consumption of LPG is expected to increase from 2.4 quads in 2012 to 3.7 quads in 2040, petrochemical feedstock consumption is forecast to increase from 0.7 quads in 2012 to 1.2 quads in 2040, and other petroleum product liquid fuel use is expected to increase from 4.9 quads in 2012 to 5.7 quads in 2040. Industrial coal use is expected to decline from 1.5 quads in 2012 to 1.4 quads in 2040. Industrial consumption of renewable energy is expected to increase from 2.4 quads in 2012 to 2.5 quads in 2040, electricity use is forecast to increase from 10.2 quads in 2012 to 12.0 quads in 2040, and natural gas consumption is forecast to increase from 8.8 quads in 2012 to 11.2 quads in 2040.

3.2.2.2 Transportation-Sector Fuel Consumption

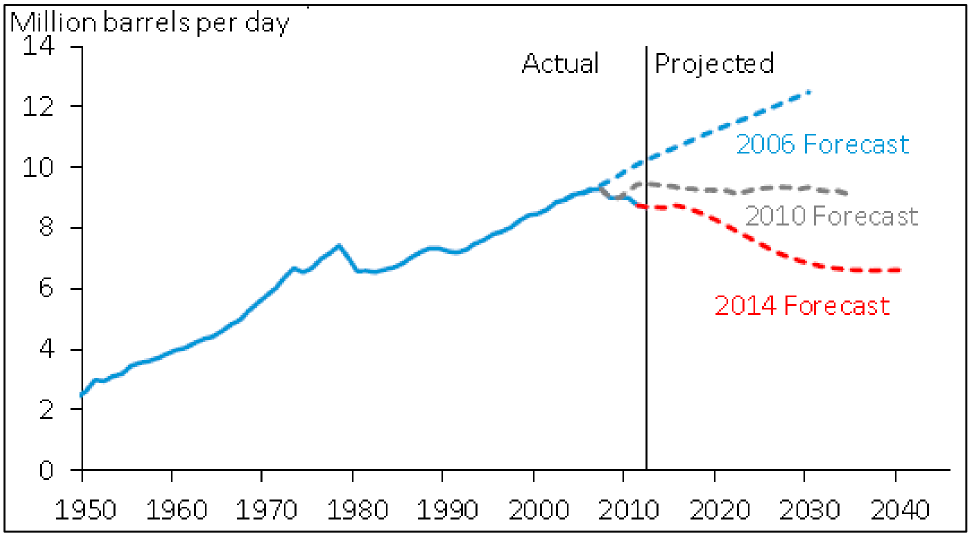
Transportation-sector fuel consumption is forecast to increase from 26.2 quads in 2012 to 26.6 quads in 2040. In 2012, petroleum supplied 92.3 percent of transportation energy demand, biofuel (mostly ethanol used in gasoline blending) supplied 4.5 percent, natural gas 3.0 percent, electricity 0.3 percent, and LPG (propane) 0.2 percent. In 2040, petroleum is expected to supply 86.8 percent of transportation energy demand, biofuel 6.0 percent, natural gas 6.3 percent, electricity 0.7 percent, and LPG 0.2 percent.

In 2012, light-duty vehicles (cars and light trucks) accounted for 57 percent of transportation energy consumption, HD vehicles accounted for 22 percent, air travel accounted for 9 percent, and other transportation (e.g., boats, rail, pipeline) accounted for 12 percent. In 2040, light-duty vehicles are expected to account for 46 percent of transportation energy consumption, HD vehicles 30 percent, air travel 12 percent, and other transportation 12 percent. The HD vehicle percentage of total transportation energy consumption is projected to increase due to an increase in HD vehicle fuel consumption and a decrease in light-duty vehicle gasoline consumption, as discussed below.

In 2012, the transportation sector accounted for 78.5 percent of total U.S. petroleum consumption. In 2040, transportation is expected to account for 74.9 percent of total U.S. petroleum consumption, with the industrial sector accounting for 22.4 percent. The residential and commercial sectors and electricity generation combined are expected to account for just 2.7 percent of U.S. petroleum consumption in 2040. With petroleum expected to be the only U.S. primary fuel with net imports in 2040, and transportation expected to account for 74.9 percent of total petroleum consumption in 2040, U.S. net energy imports through 2040 are expected to result primarily from fuel consumption by light-duty and HD vehicles.

The decline in projected transportation-sector energy consumption over the last decade has been led by a decline in projected gasoline use that reflects fuel economy and fuel efficiency improvements stemming from the model year (MY) 2012–2016 and MY 2017–2025 CAFE standards and to a lesser extent, the Phase 1 HD standards. Improvements in fuel efficiency, combined with a slower AEO 2014 (EIA 2014a) forecast growth rate for vehicle miles traveled, are why the AEO 2014 forecast much lower gasoline consumption than had been projected in the AEO 2006 and 2010 forecasts (EIA 2006, 2010), as shown in Figure 3.2.2-2. (The AEO 2015 forecast for gasoline consumption in 2040 is 4 percent higher than the AEO 2014 forecast for 2040 shown in Figure 3.2.2-2.)

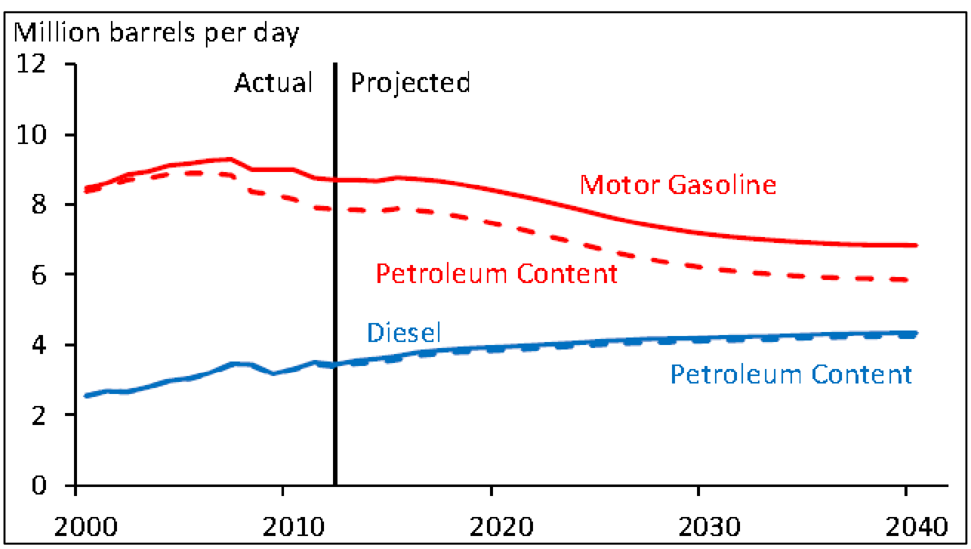
Figure 3.2.2-2. U.S. Consumption of Motor Gasoline, 1950–2040



Source: White House 2014b.

The forecast amount of petroleum consumed in gasoline is also reduced by ethanol blending in gasoline. As recently as 2000, U.S. gasoline consumption was almost entirely associated with petroleum content, but ethanol is now blended into nearly all U.S. gasoline as E10, which is 10 percent ethanol by volume, thereby reducing the petroleum content of gasoline, as shown in Figure 3.2.2-3. This figure also shows that the forecast decline in motor gasoline consumption through 2040 is expected to be partially offset by an increase in diesel fuel consumption, with forecast diesel consumption almost entirely associated with petroleum content (reflecting a relatively small forecast amount of biodiesel consumption). As noted above, this forecast does not reflect impacts of the Final Action.

Figure 3.2.2-3. U.S. Motor Gasoline and Diesel Fuel Consumption, 2000–2040



Source: White House 2014b.

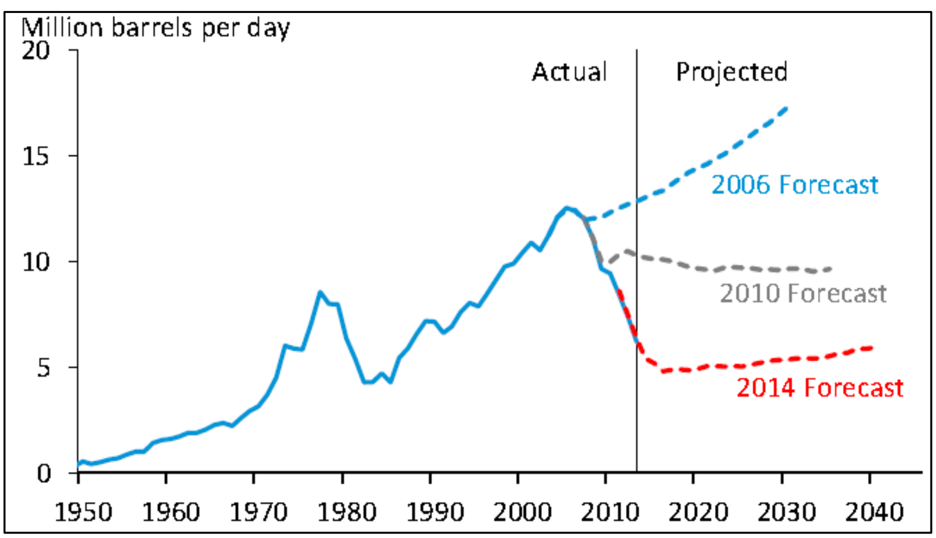
In 2012, gasoline accounted for 99.3 percent of light-duty vehicle fuel consumption and diesel accounted for 0.3 percent. In 2040, gasoline is expected to account for 93.3 percent of light-duty vehicle fuel and diesel is expected to account for 3.7 percent. By contrast, gasoline accounted for 12.8 percent of 2012 HD vehicle fuel consumption and diesel accounted for 86.4 percent. In 2040, gasoline is expected to account for 9.5 percent of HD vehicle fuel and diesel is expected to account for 83.3 percent. The share of HD vehicle fuel supplied by compressed natural gas (CNG) and liquefied natural gas (LNG) is expected to increase from 0.2 percent in 2012 to 6.3 percent in 2040. As noted above, this vehicle fuel forecast does not reflect the potential impacts of the Final Action.

3.3 HD Vehicle Fuel Efficiency and U.S. Energy Security

Section 3.2 shows that the United States is expected to have net energy exports in 2017 through 2040 for the combination of all source fuels except for petroleum. In 2040, transportation is expected to account for 75 percent of total U.S. petroleum consumption, with light-duty vehicles accounting for 46 percent of transportation energy consumption, and HD vehicles accounting for 30 percent. A forecast decline in transportation energy consumption is led by a forecast decline in gasoline use that primarily reflects the impacts of MY 2012–2016 and MY 2017–2025 light-duty CAFE standards, with gasoline expected to account for 93.3 percent of light-duty vehicle energy consumption in 2040. This forecast decline in gasoline consumption is expected to be partially offset by a forecast increase in diesel fuel consumption, with diesel expected to account for 83.3 percent of HD vehicle fuel in 2040 (this diesel forecast does not reflect impacts of the Final Action). Therefore, the Phase 2 standards for HD vehicle fuel efficiency target the segment of the affected environment for energy where there is significant potential to further reduce net petroleum imports and overall net energy imports.

As shown in Figure 3.3-1, U.S. net petroleum imports fell from a peak of over 12 million barrels per day (bpd) in 2005 to 6.2 million bpd in 2013. The president's *All-of-the-Above Energy Strategy* notes that roughly 35 percent of this steep decline in net petroleum imports is due to increases in U.S. production, and 65 percent is due to reductions in U.S. petroleum consumption (White House 2014b). The AEO 2015 forecast for U.S. petroleum net imports through 2040 is similar to the AEO 2014 forecast reflected in the president's *All-of-the-Above Energy Strategy.*

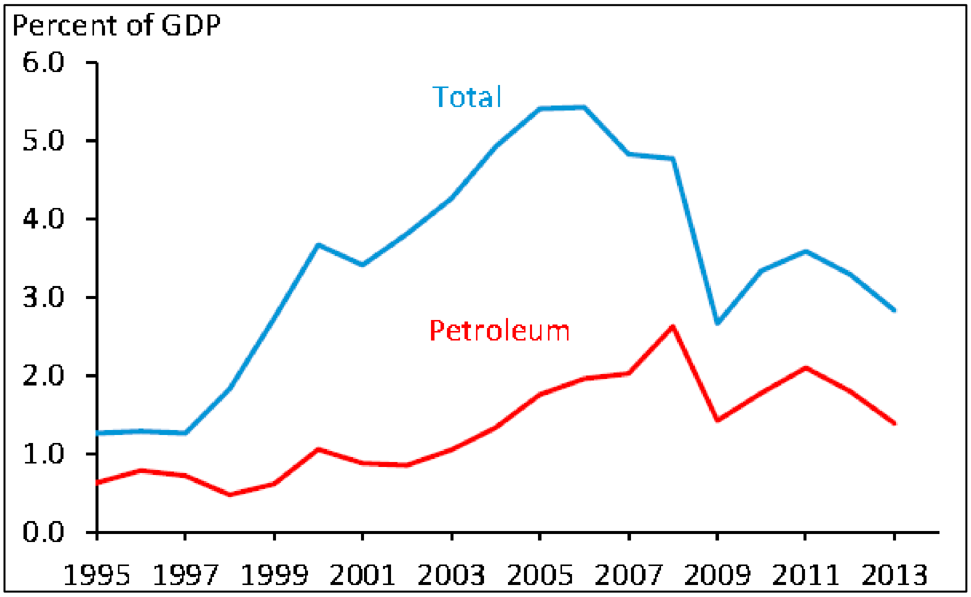
Figure 3.3-1. U.S. Petroleum Net Imports, 1950–2040



Source: White House 2014b.

The president's *All-of-the-Above Energy Strategy* also notes that the drop in net petroleum imports has accounted for more than 20 percent of a substantial decline in the U.S. trade deficit over recent years (White House 2014b), as shown in Figure 3.3-2. The total U.S. trade balance fell from 5.4 percent of GDP in 2006 (the highest recorded for the United States) to 2.8 percent by the end of 2013 (the lowest since 1999, excluding the financial crisis-affected year of 2009).

Figure 3.3-2. Total and Petroleum Trade Deficits, 1995–2013

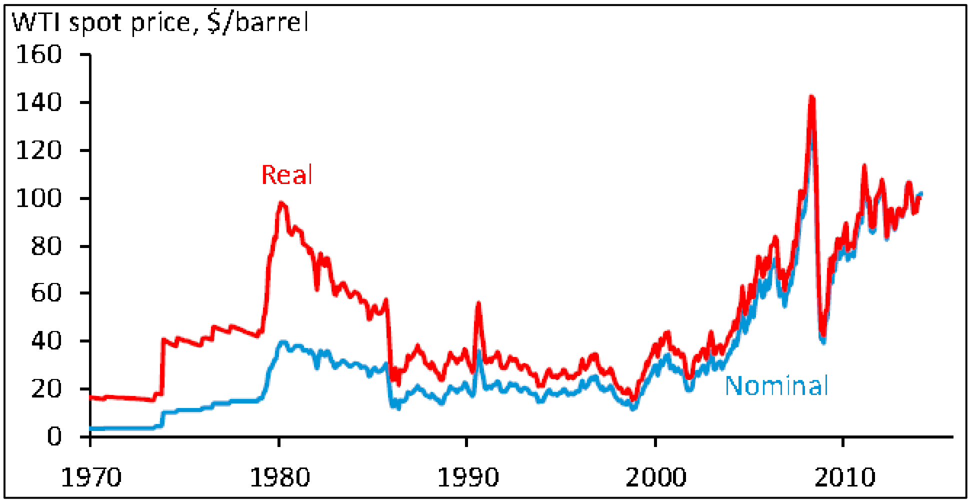


Source: White House 2014b.
GDP = gross domestic product

The impact of net petroleum imports on the U.S. trade deficit reflects both the physical volume of net imports (in bpd, as shown in Figure 3.3-1) and the prevailing price of crude oil that determines the dollar value of any given volume of net petroleum imports.

Figure 3.3-3 shows that real (inflation-adjusted) spot prices for West Texas Intermediate (WTI) crude oil were near $100 per barrel in recent years, which is comparable with peak oil prices in the late 1970s and early 1980s, and roughly three times the real price of crude oil in the 1990s. The WTI benchmark price has a significant impact on petroleum product prices including the price of motor gasoline and diesel. The WTI benchmark price fell to an average price of less than $50 in 2015, traded at an average price of less than $40 in the first quarter of 2016, and returned to a price near $50 in the second quarter of 2016 (not shown in Figure 3.3-3).

Figure 3.3-3. Nominal and Real Oil Prices (2013 $)

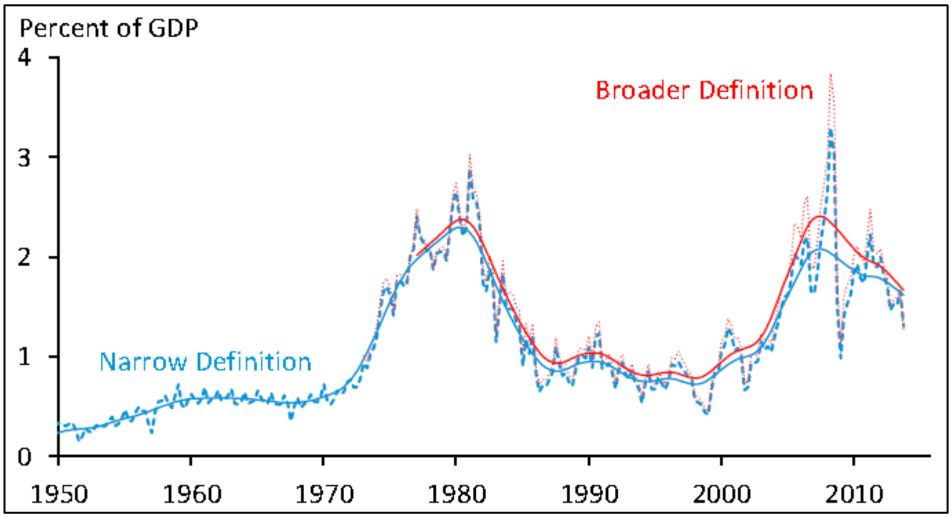


Source: White House 2014b.
WTI = West Texas Intermediate

During the 1990s, net petroleum physical imports were high but the cost of net imports as a percentage of GDP was relatively low because the real price of oil was relatively low. In 2010 through 2013, high oil prices increased the cost of net imports as a percentage of GDP even as net petroleum physical imports declined due to increasing domestic oil production, substituting biofuels and other fuels for petroleum use, and improving the energy efficiency of petroleum product consumption.

Figure 3.3-4 shows that the trend in net petroleum imports as a percentage of GDP has followed a pattern since 1970 that is closely related to the trend in real oil prices through 2013 (shown above in Figure 3.3-3). The decline in the WTI benchmark price since 2013 has further reduced net petroleum imports as a percentage of GDP (not shown in Figure 3.3-4).

Figure 3.3-4. Net Import Shares of Petroleum Products[3]



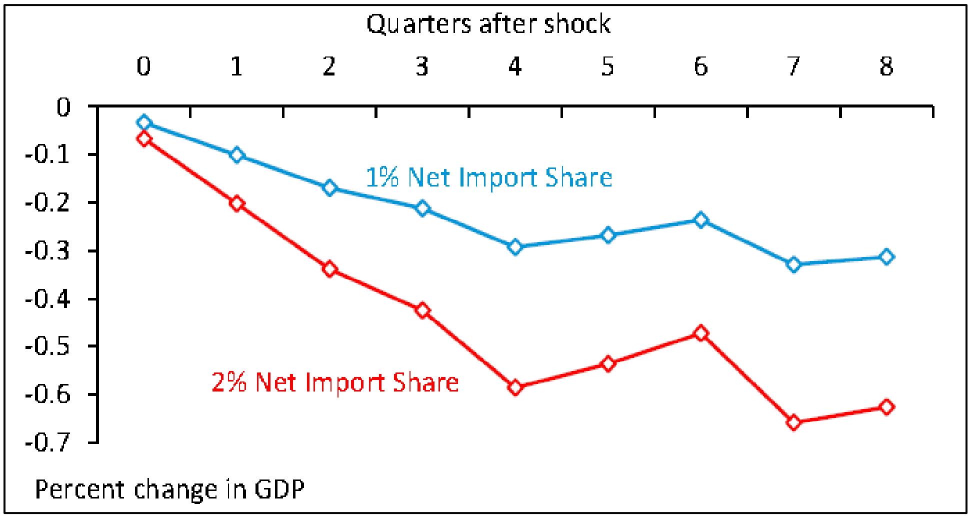
Source: White House 2014b.
GDP = gross domestic product

The United States cannot control unilaterally the global price of crude oil, which is determined by global supply and demand for oil; however, the United States can further reduce the net petroleum trade deficit by further reducing the physical volume of net petroleum imports. In addition to reducing the U.S. trade deficit, the president's *All-of-the-Above Energy Strategy* (White House 2014b) also presents an analysis of macroeconomic energy security benefits of reducing net petroleum imports associated with making the U.S. economy less vulnerable to oil price shocks arising from foreign supply disruptions. This analysis highlights a number of supply disruptions that have occurred since 1970. These disruptions resulted in rapid oil price increases of 28 to 53 percent that cut GDP growth and reduced employment over several quarters.

The analysis shows that the negative impact on GDP growth is moderated when U.S. net petroleum imports account for a smaller percent of GDP: if a 10 percent increase in oil prices occurs when net petroleum imports account for 2 percent of GDP, then the negative cumulative impact on GDP growth over subsequent quarters is about twice as severe as the same 10 percent increase in oil prices would be if net petroleum imports accounted for 1 percent of GDP, as shown in Figure 3.3-5.

[3] The narrow measure of net imports in the figure includes net imports of crude, gasoline, distillates, and fuel oil; the broader measure, available since 1973, includes naphtha, jet fuel, and other refined products, which slightly increases the net import share relative to the narrow measure but does not materially change the trend pattern.

Figure 3.3-5. Estimated Cumulative Effect of a 10 Percent Oil Price Shock on GDP



Source: White House 2014b.
GDP = gross domestic product

3.4 Environmental Consequences

Section 3.4.1 examines direct and indirect impacts on fuel consumption associated with each of the action alternatives. Section 3.4.2 examines cumulative fuel consumption impacts. Section 3.4.3 shows how the action alternatives would alter the affected energy environment described above in Section 3.2.

3.4.1 Direct and Indirect Impacts

Table 3.4.1-1 shows the direct and indirect impacts on total fuel consumption by the entire HD fleet for calendar years 2019 through 2050 from each alternative, including Alternative 1 (No Action Alternative). This analysis assumes a small forecast improvement in the average fuel efficiency of new HD vehicles MYs 2018 and beyond under the No Action Alternative, due to market-based incentives for improving fuel efficiency.[4] Table 3.4.1-1 also shows the direct and indirect fuel savings for each action alternative, compared to the No Action Alternative, through 2050, when almost the entire HD vehicle fleet is likely to be composed of vehicles subject to Phase 2 standards.

[4] As explained in Chapter 2, the analysis of direct and indirect impacts compares the action alternatives with a No Action Alternative that assumes market-based improvements in order to isolate the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the Final Rule, and not attributable to reasonably foreseeable future actions by manufacturers.

Table 3.4.1-1. HD Vehicle Fuel Consumption and Fuel Savings by Alternative from 2019–2050, Direct and Indirect Impacts

	Billion Diesel Gallon Equivalents (DGE)				
	Alt. 1 - No Action	Alt. 2	Alt. 3 - Preferred	Alt. 4	Alt. 5
Fuel Consumption					
HD Pickups and Vans	296.5	282.7	272.1	271.2	267.5
Vocational Vehicles	364.1	344.8	324.3	330.3	316.5
Tractor Trucks and Trailers	1,182.9	1,130.1	1,015.9	1,041.7	972.4
All HD Vehicles	1,843.6	1,757.6	1,612.4	1,643.3	1,556.4
Fuel Savings Compared to Alt. 1 – No Action					
HD Pickups and Vans	--	13.8	24.4	25.3	29.0
Vocational Vehicles	--	19.3	39.8	33.8	47.6
Tractor Trucks and Trailers	--	52.8	167.0	141.2	210.6
All HD Vehicles	--	85.9	231.2	200.3	287.1

Table 3.4.1-1 reports total 2019–2050 fuel consumption in diesel gallon equivalents (DGE) for diesel, gasoline, natural gas (NG), and E85 fuel, for HD pickups and vans (Classes 2b–3), vocational vehicles (Classes 2b–8), and tractor-trailers (Classes 7–8), for each alternative. Gasoline accounts for approximately 56 percent of HD pickup and van fuel use, 21 percent of vocational vehicle fuel use, and just 0.0001 percent of tractor-trailer fuel use. E85 accounts for less than 0.4 percent of HD pickup and van fuel use and E85 use is expected to be negligible for other vehicle categories. NG accounts for less than 1 percent of vocational vehicle and HD pickup and van fuel use, and NG use is expected to be negligible for tractor fuel use. Diesel accounts for approximately 43 percent of HD pickup and van fuel use, 78 percent of vocational vehicle fuel use, and 100 percent of tractor trailer fuel use.

Assuming the small forecast improvement in the average fuel efficiency of new HD vehicles MYs 2018 and beyond, total fuel consumption from 2019 through 2050 across all HD vehicle classes under the No Action Alternative is projected to be 1,843.6 billion DGE. Total projected 2019–2050 fuel consumption across the action alternatives ranges from 1,757.6 billion DGE under Alternative 2 to 1,556.4 billion DGE under Alternative 5. Less fuel would be consumed under each of the action alternatives than under the No Action Alternative, with total 2019–2050 direct and indirect fuel savings ranging from 85.9 billion DGE under Alternative 2 to 287.1 billion DGE under Alternative 5. Under the Preferred Alternative, total projected fuel consumption from 2019–2050 would be 1,612.4 billion DGE, and direct and indirect fuel savings compared with the No Action Alternative would be 231.2 billion DGE. As noted in Section 2.2, Alternative 4 is less stringent than Alternative 3 (Preferred Alternative) in this FEIS for some vehicle categories. This change from the DEIS reflects FEIS standards for the Preferred Alternative that are more stringent than the DEIS proposed standards for the Preferred Alternative, whereas standards for Alternative 4 in this FEIS are the same as the Alternative 4 standards in the DEIS.

3.4.2 Cumulative Impacts

Table 3.4.2-1 shows the cumulative impacts on total fuel consumption by the entire HD fleet for calendar years 2019 through 2050 from each alternative, including the No Action Alternative. It also shows the cumulative fuel savings for each action alternative, compared to the No Action Alternative, through 2050. Total 2019–2050 fuel consumption for each action alternative in this table is the same as shown for the corresponding action alternative in Table 3.4.1-1.

Table 3.4.2-1. HD Vehicle Fuel Consumption and Fuel Savings by Alternative from 2019–2050, Cumulative Impacts

	Billion Diesel Gallon Equivalents (DGE)				
	Alt. 1 - No Action	Alt. 2	Alt. 3 - Preferred	Alt. 4	Alt. 5
Fuel Consumption					
HD Pickups and Vans	298.6	282.7	272.1	271.2	267.5
Vocational Vehicles	364.1	344.8	324.3	330.3	316.5
Tractor Trucks and Trailers	1,203.2	1,130.1	1,015.9	1,041.7	972.4
All HD Vehicles	1,865.9	1,757.6	1,612.4	1,643.3	1,556.4
Fuel Savings Compared to Alt. 1 - No Action					
HD Pickups and Vans	--	15.9	26.5	27.4	31.1
Vocational Vehicles	--	19.3	39.8	33.8	47.6
Tractor Trucks and Trailers	--	73.0	187.3	161.4	230.8
All HD Trucks	--	108.3	253.5	222.6	309.4

The No Action Alternative fuel consumption is higher in Table 3.4.2-1 than in Table 3.4.1-1 because the No Action fuel consumption numbers in Table 3.4.2-1 do not reflect any forecast improvement in the average fuel efficiency of new HD vehicles in MYs 2018 and beyond. As a result, the fuel savings estimates in Table 3.4.2-1 reflect the cumulative impact of reasonably foreseeable improvements in fuel efficiency after 2018 due to market-based incentives in addition to the direct and indirect impacts of the Phase 2 HD standards associated with each action alternative.

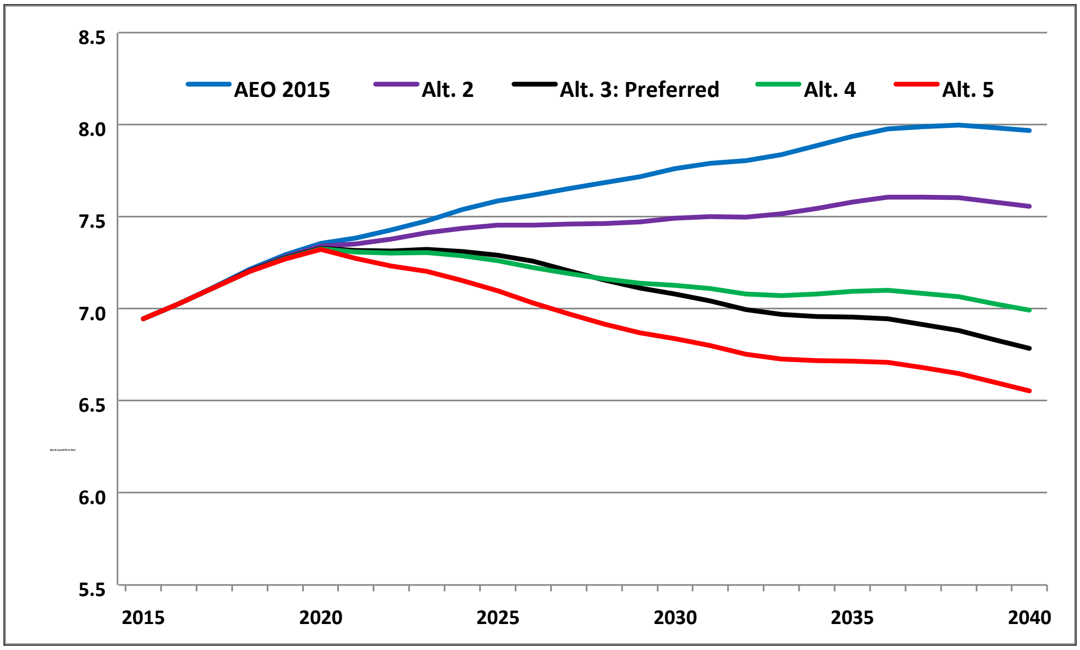
Assuming no improvement in the average fuel efficiency of new HD vehicles MYs 2018 and beyond, total fuel consumption from 2019 through 2050 across all HD vehicle classes under the No Action Alternative is projected to amount to 1,865.9 billion DGE. Total 2019–2050 projected fuel consumption across alternatives ranges from 1,757.6 billion DGE under Alternative 2 to 1,556.4 billion DGE under Alternative 5. Less fuel would be consumed under each of the action alternatives than under the No Action Alternative, with total 2019–2050 cumulative fuel savings ranging from 108.3 billion DGE under Alternative 2 to 309.4 billion DGE under Alternative 5. Under the Preferred Alternative, total projected fuel consumption from 2019–2050 would be 1,612.4 billion DGE, and cumulative fuel savings compared with the No Action Alternative would be 253.5 billion DGE. As noted above and in Section 2.2, the FEIS standards for the Preferred Alternative are more stringent than the DEIS proposed standards for the Preferred Alternative for some vehicle categories, whereas standards for Alternative 4 in this FEIS are the same as Alternative 4 standards in the DEIS.

3.4.3 Overall Benefits of Joint National Program

The affected environment for U.S. energy production and consumption described in Section 3.2 reflects the substantial impact of past vehicle fuel efficiency actions, including National Program standards for light-duty passenger cars and light trucks for MYs 2012–2016 and 2017–2025, and Phase 1 HD standards for MY 2014–2018. As noted in Section 3.2, these improvements in fuel efficiency, combined with slower forecast growth in vehicle miles traveled, are why the AEO 2014 forecast much lower gasoline consumption than had been projected in the AEO 2010, as shown in Figure 3.2.2-2.

The overall benefits of 2012–2025 light-duty and 2014–2018 HD vehicle National Program standards are also evident in the forecast decline in motor gasoline consumption and the historically small increase in diesel fuel consumption through 2040, shown in Figure 3.2.2-3. Phase 2 HD standards would have only a very small incremental impact on forecast motor gasoline (and E85 and NG) consumption, because HD vehicles account for only a small fraction of motor gasoline use, but Phase 2 HD standards would have a more substantive impact on forecast transportation diesel fuel consumption, as shown in Figure 3.4.3-1.

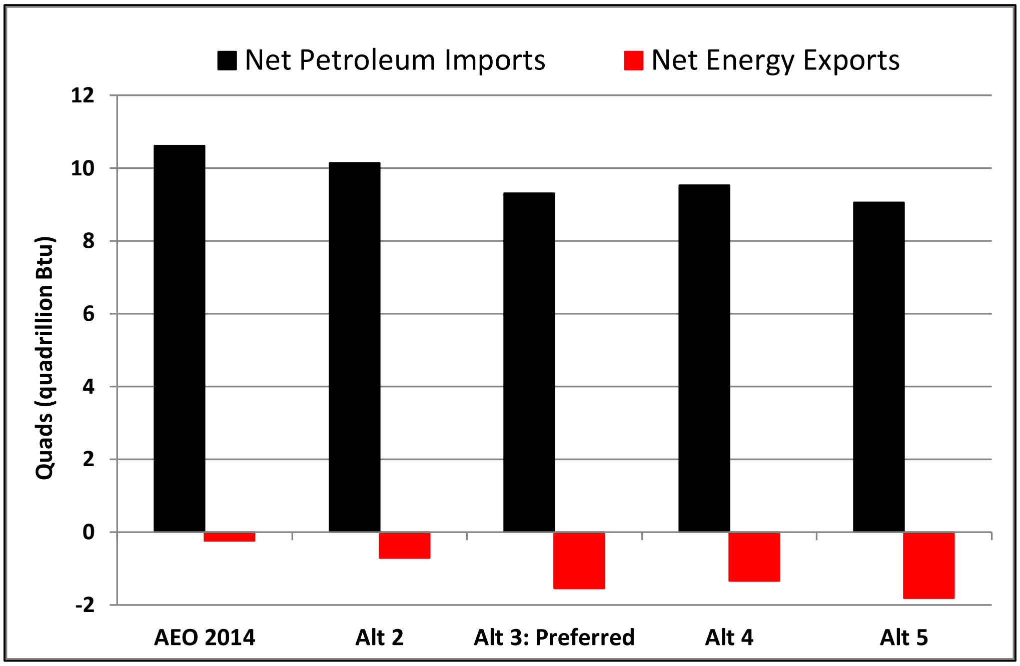
Figure 3.4.3-1. Phase 2 HD Impact on U.S. Transportation Diesel Fuel Consumption, 2015–2040



In fact, the Preferred Alternative (and Alternatives 4 and 5) would bend the AEO 2015 forecast trajectory for diesel consumption, resulting in a forecast decline in U.S. transportation diesel use beginning in the early 2020s and running through 2040. Total forecast transportation diesel consumption in 2040 under the Preferred Alternative would be below the transportation diesel consumption level in 2015.

Section 3.2 shows that the combination of increased U.S. energy production, more electricity generation from renewables, and gains in energy efficiency are expected to achieve a small level of net energy exports in 2040, and a large reduction in net petroleum imports through 2040, with net energy exports forecast in 2017 through 2040 for the combination of all source fuels except for petroleum. The Phase 2 HD vehicle standards are just one component of the president's *All-of-the-Above Energy Strategy*, but the incremental impact of Phase 2 standards would further reduce U.S. net petroleum imports and increase overall net energy exports, as shown in Figure 3.4.3-2. The Final Rule has the potential to reduce forecast net petroleum imports by 12 percent in 2040, and increase overall net energy exports in 2040 from 0.24 quads to 1.8 quads.

Figure 3.4.3-2. Phase 2 HD Impact on Projected U.S. Net Petroleum Imports and Net Energy Exports in 2040



CHAPTER 4 AIR QUALITY

This rulemaking Action (including Alternative 1 [No Action Alternative], Alternative 2, Alternative 3 [Preferred Alternative], Alternative 4, and Alternative 5) will affect air pollutant emissions and air quality, which in turn, will affect public health and welfare and the natural environment. Section 4.1.1 describes the relevant air pollutants, the standards that regulate levels of these pollutants in the ambient air, their health effects, and the regulations that limit pollutant emissions rates from vehicles. Section 4.1.2 describes the approaches and methods that NHTSA used to estimate the impacts of the Final Action, including the national and regional analyses, the timeframes for analysis, treatment of incomplete or unavailable information, allocation of estimated emissions to nonattainment areas, and estimates of health outcomes and monetized benefits. Section 4.2.1 describes the direct and indirect impacts of the Final Action. Specifically, Section 4.2.1.1 provides overviews of the estimated changes in criteria pollutant emissions, toxic air pollutant emissions, health effects and monetized health benefits due to the rulemaking, while Sections 4.2.1.2 through 4.2.1.6 discuss these impacts in detail for each alternative. Section 4.2.2 describes the cumulative impacts of the rulemaking, covering the same information discussed in Section 4.2.1 but given the assumptions of the cumulative impact analysis (explained in Section 2.3).

4.1 Affected Environment

4.1.1 Relevant Pollutants and Standards

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, 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 origins. 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, heart and lung diseases, and damage to the immune, neurological, reproductive, and respiratory systems. In extreme cases, it can even cause death (EPA 2012a).

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, the U.S. Environmental Protection Agency (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] The criteria pollutants analyzed in this EIS are 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 (PM10) and 2.5 microns (PM2.5, or fine particles), and lead. Vehicles do not directly emit ozone, but this pollutant is evaluated based on emissions of the ozone precursor pollutants nitrogen oxides (NO_X) and volatile organic compounds (VOCs). 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.

Total emissions from on-road mobile sources (highway vehicles) 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 2013, emissions from on-road mobile sources declined 85 percent for CO, 60 percent for NO_X, 43 percent for PM2.5, 44 percent for PM10, 89 percent for SO_2, and 87 percent for VOCs. Nevertheless, the U.S. transportation sector remains a major source of emissions of certain criteria pollutants or their chemical precursors. On-road mobile sources are responsible for 24,796,000 tons per year of CO (34 percent of total U.S. emissions), 185,000 tons per year (3 percent) of PM2.5 emissions, and 268,000 tons per year (1 percent) of PM10 emissions (EPA 2013a). HD vehicles contribute 6 percent of U.S. highway emissions of CO, 66 percent of highway emissions of PM2.5, and 55 percent of highway emissions of PM10 (Davis et al. 2013). Almost all of the PM in motor vehicle exhaust is PM2.5 (Gertler et al. 2000, EPA 2013b); therefore, this analysis focuses on PM2.5 rather than PM10. On-road mobile sources also contribute 2,161,000 tons per year (12 percent of total nationwide emissions) of VOCs and 5,010,000 tons per year (38 percent) of NO_X emissions, which are chemical precursors of ozone (EPA 2013a). HD vehicles contribute 8 percent of U.S. highway emissions of VOCs and 50 percent of NO_X (Davis et al. 2013). In addition, NO_X is a PM2.5 precursor and VOCs can be PM2.5 precursors.[2] SO_2 and other oxides of sulfur (SO_X) are important because they contribute to the formation of PM2.5 in the atmosphere; however, on-road mobile sources account for less than 0.56 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. Therefore, this analysis does not address lead.

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, NAAQS specify different

[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* 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.

[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 PM2.5. Highway vehicle emissions are large contributors to nitrate formation nationally (EPA 2004a).

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

Pollutant	Primary Standards		Secondary Standards	
	Level[a]	Averaging Time	Level[a]	Averaging Time
Carbon monoxide (CO)	9 ppm (10 mg/m^3)	8 hours[b]	None	
	35 ppm (40 mg/m^3)	1 hour[b]		
Lead	0.15 µg/m^3	Rolling 3-month average	Same as Primary	
Nitrogen dioxide (NO_2)	0.053 ppm (100 µg/m^3)	Annual (arithmetic mean)	Same as Primary	
	0.100 ppm (188 µg/m^3)	1 hour[c]	None	
Particulate matter (PM10)	150 µg/m^3	24 hours[d]	Same as Primary	
Particulate matter (PM2.5)	12.0 µg/m^3	Annual (arithmetic mean)[e]	15.0 µg/m^3	Annual (arithmetic mean)[e]
	35 µg/m^3	24 hours[f]	Same as Primary	
Ozone	0.070 ppm	8 hours[g]	Same as Primary	
Sulfur dioxide (SO_2)	0.075 ppm (200 µg/m^3)	1 hour[h]	0.5 ppm (1,300 µg/m^3)	3 hours[b]

Notes:

[a] 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.

[b] Not to be exceeded more than once per year.

[c] 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).

[d] Not to be exceeded more than once per year on average over 3 years.

[e] To attain this standard, the 3-year average of the weighted annual mean PM2.5 concentrations from single or multiple community-oriented monitors must not exceed 12.0 µg/m^3 for the primary standard and 15.0 µg/m^3 for the secondary standard.

[f] 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).

[g] 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 0.070 ppm (effective December 28, 2015).

[h] 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.

Source: 40 CFR Part 50, as presented in EPA 2016a.

CFR = Code of Federal Regulations; EPA = U.S. Environmental Protection Agency; PM10 = particulate matter with a nominal aerodynamic diameter equal to or less than 10 microns; PM2.5 = particulate matter with a nominal aerodynamic diameter equal to or less than 2.5 microns

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 ($\mu g/m^3$) 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.

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 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 from highway vehicles (EPA 2007, FHWA 2012). DPM is a component of exhaust from diesel-fueled vehicles and falls almost entirely within the PM2.5 particle-size class. On-road mobile sources are responsible for 57,440,375 tons per year (4 percent of total U.S. emissions) of acetaldehyde emissions, 4,940,766 tons per year (5 percent) of acrolein emissions, 118,251,994 tons per year (22 percent) of benzene emissions, 19,735,566 tons per year (16 percent) of 1,3-butadiene emissions, and 86,046,243 tons per year (3 percent) of formaldehyde emissions (EPA 2011).[4]

Vehicle-related sources of air pollutants include exhaust emissions, evaporative emissions, resuspension of road dust, and tire and brake wear. Locations in close proximity to major roadways generally have elevated concentrations of many air pollutants emitted from motor vehicles. Hundreds of such studies have been published in peer-reviewed journals, concluding that concentrations of CO, nitric oxide, NO_2, benzene, aldehydes, particulate matter, black carbon, and many other compounds are elevated in ambient air within approximately 300 to 600 meters (about 1,000 to 2,000 feet) of major roadways. Studies that focused on measurements during meteorological conditions that tend to inhibit the dispersion of emissions have found that concentrations of traffic-generated air pollutants can be elevated for as much as 2,600 meters (about 8,500 feet) downwind of roads under such meteorological conditions (Hu et al. 2009, 2012). The highest concentrations of most pollutants emitted directly by motor vehicles are found at locations within 50 meters (about 165 feet) of the edge of a roadway's traffic lanes.

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[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 2007).

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

Air pollution near major roads has been shown to increase the risk of adverse health effects in populations who live, work, or attend school near major roads.[5] A 2013 study estimated that 19 percent of the U.S. population (over 59 million people) lived within 500 meters (about 1,600 feet) of major roads (those with at least 25,000 annual average daily traffic), while about 3.2 percent of the population (10 million people) lived within 100 meters (about 300 feet) of such roads (Rowangould 2013). Another 2013 study estimated that 3.7 percent of the U.S. population (about 11 million people) lived within 150 meters (about 500 feet) of interstate highways, or other freeways and expressways (Boehmer et al. 2013). Because of the large number of people who live near major roads, it is important to understand how traffic-generated pollutants collectively affect the health of exposed populations (EPA 2012b).

In the past 15 years, many studies have been published with results reporting that populations who live, work, or go to school near high-traffic roadways experience higher rates of numerous adverse health effects, compared to populations far away from major roads.[6] In addition, numerous studies have found adverse health effects associated with spending time in traffic, such as commuting or walking along high-traffic roadways (Laden et al. 2007, Peters et al. 2004, Zanobetti et al. 2009, Dubowsky Adar et al. 2007). The health outcomes with the strongest evidence of linkages with traffic-associated air pollutants are respiratory effects, particularly in asthmatic children, and cardiovascular effects.

Numerous reviews of this body of health literature have been published as well. In 2010, an expert panel of the Health Effects Institute (HEI) published a review of hundreds of exposure, epidemiology, and toxicology studies (HEI 2010). The panel rated how the evidence for each type of health outcome supported a conclusion of a causal association with traffic-associated air pollution as either “sufficient,” “suggestive but not sufficient,” or “inadequate and insufficient.” The panel categorized evidence of a causal association for exacerbation of childhood asthma as “sufficient,” and categorized evidence of a causal association for new onset asthma as between “sufficient” and as “suggestive but not sufficient.” The panel categorized evidence linking traffic-associated air pollutants with exacerbation of adult respiratory symptoms and lung function decrement as “suggestive of a causal association.” It categorized as “inadequate and insufficient” evidence of a causal relationship between traffic-related air pollution and health care utilization for respiratory problems, new onset adult asthma, chronic obstructive pulmonary disease, non-asthmatic respiratory allergy, and cancer in adults and children. Other literature reviews have been published with conclusions generally similar to the HEI panel’s (Boothe and Shendell 2008, Sun et al. 2014). However, researchers from the U.S. Centers for Disease Control and Prevention (CDC) recently published a systematic review and meta-analysis of studies evaluating the risk of childhood leukemia associated with traffic exposure, and reported positive associations between “postnatal” proximity to traffic and leukemia risks, but no such association for “prenatal” exposures (Boothe et al.2014).

There are other possible adverse health outcomes resulting from high-traffic exposure that are less studied and still lack sufficient evidence to draw definitive conclusions. Among these less studied potential outcomes are neurological impacts (e.g., autism and reduced cognitive function) and

[5] Most of the information in the remainder of this section appeared originally in the EPA 2014 Final Rule establishing Tier 3 motor vehicle emissions and fuel standards. *See* Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule, 79 FR 23414 (April 28, 2014).

[6] The Tier 3 Final Rule reported that in the widely-used PubMed database of health publications, between January 1, 1990 and August 18, 2011, 605 publications contained the keywords “traffic, pollution, epidemiology,” with approximately half the studies published after 2007.

reproductive outcomes (e.g., preterm birth, low birth weight) (Volk et al. 2011, Franco-Suglia et al. 2007, Power et al. 2011, Wu et al. 2011).

In addition to reporting health outcomes, particularly cardiopulmonary effects, numerous studies suggest mechanisms by which traffic-related air pollution affects health and leads to those reported outcomes. Numerous studies indicate that near-roadway exposures may increase systemic inflammation, affecting organ systems, including blood vessels and lungs (Riediker 2007, Alexeef et al. 2011, Eckel et al. 2011, Zhang et al. 2009). Long-term exposures in near-road environments have been associated with inflammation-associated conditions, such as atherosclerosis and asthma (Adar et al. 2010, Kan et al. 2008, McConnell et al. 2010).

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 5.4 addresses the major greenhouse gases (GHGs)—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O); this air quality analysis does not include these GHGs.

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 EPA (2012c). The most recent EPA technical reports and *Federal Register* notices for NAAQS reviews provide more information on the health effects of criteria pollutants (EPA 2013c).

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 volatile organic compounds (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 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 (2006), 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; few studies have focused on their long-term effects on vegetation and the potential for the metabolites[7] 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, 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 (black carbon).[8] 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,[9] 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, degrading paints, and deteriorating building materials (especially concrete and limestone). Section 7.2 provides more information about materials damage and soiling impacts.

As noted above, EPA regulates PM according to two particle-size classifications, PM10 and PM2.5. This analysis considers only PM2.5 because almost all of the PM emitted in exhaust from HD vehicles is PM2.5. EPA classifies DPM as an MSAT, so it is addressed in the air toxics section (*see* Section 4.1.1.2.5).

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[7] Other molecules that are formed as the initial compounds break down and are transformed through metabolism.

[8] Elemental carbon and black carbon are similar forms of fine PM and are considered synonymous for purposes of this analysis. The term *elemental carbon* describes carbonaceous particles based on chemical composition rather than light-absorbing characteristics. The term *black carbon* describes particles of mostly pure carbon that absorb solar radiation at all wavelengths (EPA 2012d). The carbon content of a sample of PM can be described by either term depending on the test method used: typically, the result for a sample tested by thermal or wet chemical methods is termed "elemental carbon" while the result for a sample tested by optical methods is termed "black carbon" (Andreae and Gelencsér 2006).

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

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.[10] 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. Epidemiological 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. Therefore, this analysis does not address lead.

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 (constriction of the airways). Asthmatics are more sensitive to the effects of SO_2, likely because of preexisting bronchial inflammation. 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.

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 outcomes, including all-cause (non-

[10] Highway motor vehicles overall accounted for 34 percent of national CO emissions in 2011 (EPA 2013a). Passenger cars and light trucks accounted for approximately 89 percent of the CO emissions from highway motor vehicles (EPA 2013b) while HD vehicles accounted for most of the remaining 11 percent.

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 ozone and acid rain, and can affect terrestrial and aquatic ecosystems.

4.1.1.2 Health Effects of Mobile Source Air Toxics

Sections 4.1.1.2.1 through 4.1.1.2.6 briefly describe the health effects of the six priority MSATs analyzed in this EIS. This information is adapted from the Preamble to the EPA Tier 3 Motor Vehicle Emission and Fuel Standards Rule.[11]

Motor vehicle emissions contribute to ambient levels of air toxics known or suspected to be human or animal carcinogens, or that have non-cancer health effects. The population experiences an elevated risk of cancer and other non-cancer health effects from exposure to air toxics (EPA 2005). 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 2005). 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 discussed 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 is currently in the draft development phase of the hazard identification. The expected completion date is to be determined (EPA 2014a).

The primary non-cancer 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 non-cancer health hazards from inhalation exposure to acetaldehyde on the same schedule noted above.

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

[11] Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule, 79 FR 23414 (April 28, 2014).

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 milligram 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.

IARC determined that acrolein was not classifiable as to its carcinogenicity in humans (IARC 1995), and 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).

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 non-cancer 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 non-cancer 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 reported any evaluation of these newer data (EPA 2013d).

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 deoxyribonucleic acid [DNA]). 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)

Diesel exhaust consists of a complex mixture composed of CO_2, oxygen, nitrogen, water vapor, CO, nitrogen compounds, sulfur compounds and numerous low-molecular-weight hydrocarbons. A number of these gaseous hydrocarbon components are individually known to be toxic, including aldehydes, benzene and 1,3-butadiene. The DPM present in diesel exhaust consists mostly of fine particles (smaller than 2.5 microns), of which a significant fraction is ultrafine particles (smaller than 0.1 micron). These particles have a large surface area, which makes them an excellent medium for adsorbing organics, and their small size makes them highly respirable. Many of the organic compounds present in the gases and on the particles, such as polycyclic organic matter, are individually known to have mutagenic and carcinogenic properties.

DPM also includes elemental carbon (i.e., black carbon) particles emitted from diesel engines. EPA has not provided special status, such as an NAAQS or other health-protective measures, for black carbon, but addresses black carbon in terms of PM2.5 and DPM emissions.

Diesel exhaust varies significantly in chemical composition and particle sizes between different engine types (heavy-duty, light-duty), engine operating conditions (idle, acceleration, deceleration), and fuel formulations (high/low sulfur fuel). Also, there are emissions differences between on-road and non-road engines because the non-road engines are generally of older technology. After being emitted in the engine exhaust, diesel exhaust undergoes dilution, as well as chemical and physical changes in the atmosphere. The lifetime for some of the compounds present in diesel exhaust ranges from hours to days.

In EPA's 2002 *Diesel Health Assessment Document* (Diesel HAD) (EPA 2002d), exposure to diesel exhaust was classified as likely to be carcinogenic to humans by inhalation from environmental exposures, in accordance with the revised draft 1996–1999 EPA cancer guidelines (EPA 1999a). A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) had made similar hazard classifications prior to 2002. EPA also concluded in the 2002 Diesel HAD that it was not possible to calculate a cancer unit risk for diesel exhaust due to limitations in the exposure data for the occupational groups or the absence of a dose-response relationship.

In the absence of a cancer unit risk, the Diesel HAD sought to provide additional insight into the significance of the diesel exhaust cancer hazard by estimating possible ranges of risk that might be present in the population. An exploratory analysis was used to characterize a range of possible lung cancer risk. The outcome was that environmental risks of cancer from long-term diesel exhaust exposures could plausibly range from as low as 10^{-5} to as high as 10^{-3}. Because of uncertainties, the analysis acknowledged that the risks could be lower than 10^{-5}, and a zero risk from diesel exhaust exposure could not be ruled out.

Non-cancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern to EPA. EPA derived a diesel exhaust reference concentration (RfC) from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects. The RfC is 5 $\mu g/m^3$ for diesel exhaust measured as DPM. This RfC does not consider allergenic effects such as those associated with asthma or immunologic effects or the potential for cardiac effects. There was emerging evidence in 2002, discussed in the Diesel HAD, that exposure to diesel exhaust can exacerbate these effects, but the exposure-response data were lacking at that time to derive an RfC based on these then-emerging considerations. The EPA Diesel HAD states, "With [diesel particulate matter] being a ubiquitous component of ambient PM, there is an uncertainty about the adequacy of the existing [diesel exhaust] non-cancer database to identify all of the pertinent [diesel exhaust]-caused non-cancer health hazards." The Diesel HAD also notes "that acute exposure to [diesel exhaust] has been associated with irritation of the eye, nose, and throat, respiratory symptoms (cough and phlegm), and neurophysiological symptoms such as headache, lightheadedness, nausea, vomiting, and numbness or tingling of the extremities." The Diesel HAD notes that the cancer and non-cancer hazard conclusions applied to the general use of diesel engines then on the market and as cleaner engines replace a substantial number of existing ones, the applicability of the conclusions would need to be reevaluated.

The Diesel HAD also briefly summarizes health effects associated with ambient PM and discusses EPA's then-annual PM2.5 NAAQS of 15 $\mu g/m^3$. In 2012, EPA revised the annual PM2.5 NAAQS to 12 $\mu g/m^3$. There is a large and extensive body of human data showing a wide spectrum of adverse health effects associated with exposure to ambient PM, of which diesel exhaust is an important component. The PM2.5 NAAQS is designed to provide protection from the non-cancer health effects and premature mortality attributed to exposure to PM2.5. The contribution of diesel PM to total ambient PM varies in different regions of the country and also, within a region, from one area to another. The contribution can be high in near-roadway environments, for example, or in other locations where diesel engine use is concentrated.

Since 2002, several new studies have been published, which continue to report increased lung cancer risk with occupational exposure to diesel exhaust from older engines. Of particular note since 2011, are three new epidemiology studies that have examined lung cancer in occupational populations, for example, truck drivers, underground non-metal miners and other diesel-motor-related occupations (Garshick et al. 2012, Silverman et al. 2012, Olsson et al. 2011). These studies reported increased risk of lung cancer with exposure to diesel exhaust with evidence of positive exposure-response relationships to varying degrees. These newer studies—along with others that have appeared in the scientific literature—add to the evidence EPA evaluated in the 2002 Diesel HAD and further reinforces the concern that diesel exhaust exposure likely poses a lung cancer hazard. The findings from these newer studies do not necessarily apply to newer technology diesel engines since the newer engines have large reductions in the emissions constituents compared to older-technology diesel engines.

In light of the growing body of scientific literature evaluating the health effects of exposure to diesel exhaust, in June 2012, the World Health Organization's International Agency for Research on Cancer (IARC), a recognized international authority on the carcinogenic potential of chemicals and other agents, evaluated the full range of cancer-related health effects data for diesel engine exhaust. IARC concluded that diesel exhaust should be regarded as "carcinogenic to humans" (IARC 2013). This designation was an update from its 1988 evaluation that considered the evidence to be indicative of a "probable human carcinogen."

4.1.1.2.6 Formaldehyde

In 1991, EPA concluded that formaldehyde is a carcinogen based on nasal tumors in animal bioassays (EPA 1989). EPA developed an Inhalation Unit Risk for cancer and a Reference Dose for oral non-cancer effects and posted them in the IRIS database. Since that time, the National Toxicology Program and IARC have concluded that formaldehyde is a known human carcinogen (NTP 2011, IARC 2006, and IARC 2012).

The conclusions by IARC and the National Toxicology Program reflect the results of epidemiologic research published since 1991, in combination with previous animal, human, and mechanistic evidence. Research by the National Cancer Institute reported an increased risk of nasopharyngeal (nose and throat) cancer and specific lymphohematopoietic (lymph and blood) malignancies among workers exposed to formaldehyde (Hauptmann et al. 2003, 2004, and Beane Freeman et al. 2009). A National Institute of Occupational Safety and Health study of garment workers also reported increased risk of death due to leukemia among workers exposed to formaldehyde (Pinkerton et al. 2004). Extended follow-up of a cohort of British chemical workers did not report evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported (Coggon et al. 2003). Finally, a study of embalmers reported formaldehyde exposures to be associated with an increased risk of myeloid (bone marrow cell) leukemia, but not brain cancer (Hauptmann et al. 2009).

Health effects of formaldehyde in addition to cancer were reviewed by the Agency for Toxics Substances and Disease Registry in 1999 (ATSDR 1999) and supplemented in 2010 (ATSDR 2010), and by the World Health Organization (World Health Organization 2002). These organizations reviewed the literature concerning effects on the eyes and respiratory system, the primary point of contact for inhaled formaldehyde, including sensory irritation of eyes, and respiratory tract, pulmonary function, nasal histopathology, and immune system effects. In addition, research on reproductive and developmental effects and neurological effects were discussed along with several studies that suggest formaldehyde may increase the risk of asthma, particularly in the young. EPA released a draft Toxicological Review of Formaldehyde–Inhalation Assessment through the IRIS program for peer review by the National Research Council (NRC) and public comment in June 2010 (EPA 2010a). The draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The NRC released their review report in April 2011 (NRC 2011a). The EPA is currently revising the draft assessment in response to this review (EPA 2014b).

4.1.1.3 Vehicle Emissions Standards

EPA has established criteria pollutant emissions standards for vehicles under the CAA. EPA has tightened these emissions standards over time as more effective emissions-control technologies have become available. These stricter standards for passenger cars and light trucks and for HD 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 limits than under the previous Tier 1 standards. By 2006, U.S. refiners and importers of gasoline were required under the Tier 2 standards to manufacture gasoline with an average sulfur level of 30 ppm, a 90 percent reduction from earlier sulfur levels. These fuels enable post-2006 MY vehicles to use emissions-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. On April 28, 2014, EPA issued a Final Rule establishing Tier 3 motor vehicle emissions and fuel standards.[12] The Tier 3 vehicle standards reduce both tailpipe and evaporative emissions from passenger cars, light-duty trucks, medium-duty passenger vehicles, and Classes 2b–3 heavy-duty vehicles. Starting in 2017, Tier 3 sets new vehicle emissions standards and lowers the sulfur content of gasoline, considering the vehicle and its fuel as an integrated system. The Tier 3 program will require an approximate 60 percent reduction in new Classes 2b–3 vehicle NO_X, PM, VOCs and formaldehyde emissions. The Tier 3 gasoline sulfur standard will make emissions-control systems more effective for both existing and new vehicles, and will enable more stringent vehicle emissions standards (EPA 2014c).

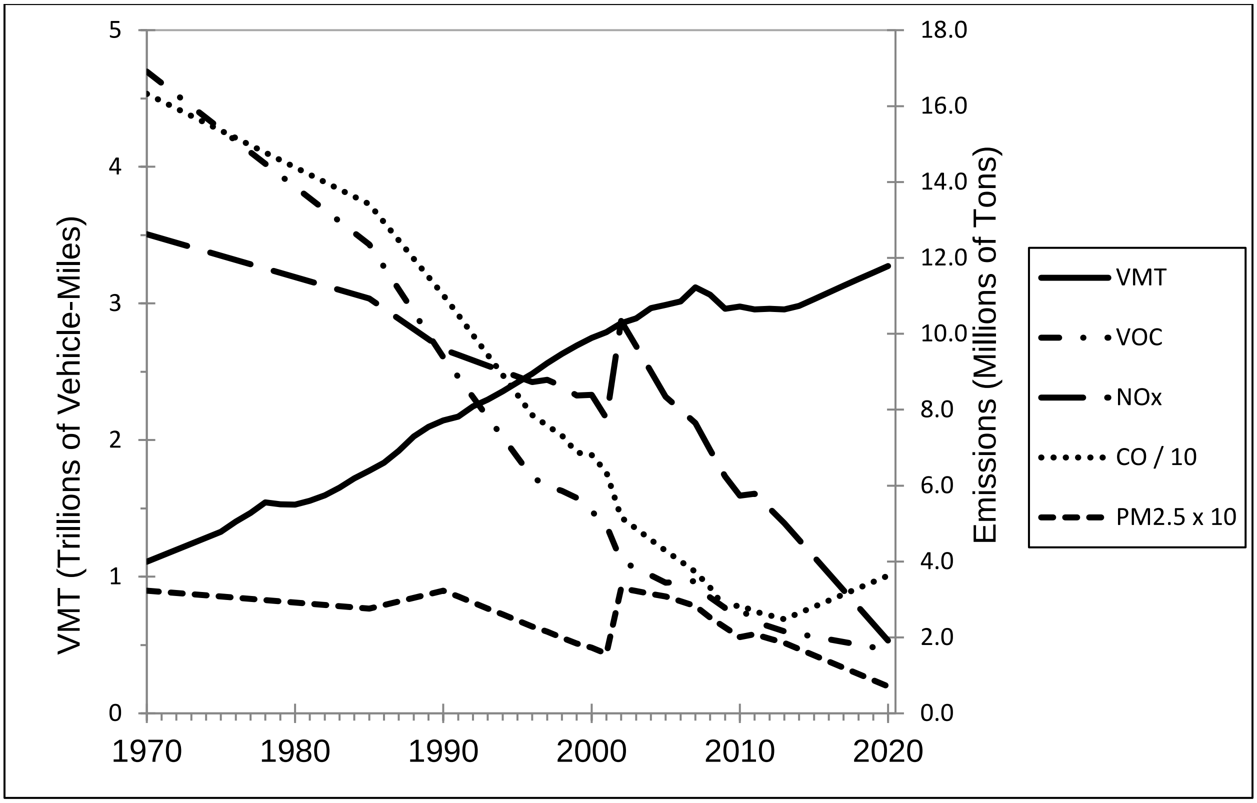
EPA adopted new emissions-control requirements for heavy-duty highway engines and vehicles on October 6, 2000 (65 *FR* 59896) and January 18, 2001 (66 *FR* 5002). These rules also required that the Nation's refiners and importers of diesel fuel manufacture diesel fuel with sulfur levels capped at 15 ppm, an approximately 97-percent reduction from the previous maximum of 500 ppm. This fuel, known as ultra-low-sulfur diesel fuel, enables post-2006 MY heavy-duty vehicles to use emissions controls that reduce exhaust (tailpipe) emissions of NO_X by 95 percent and PM by 90 percent, compared to 2003 model year levels. As a result of these programs, new trucks meeting current emissions standards emit 98 percent less NO_X and 99 percent less PM than new trucks emitted 20 years ago.[13] Figure 4.1.1-1 illustrates current trends in travel and emissions from highway vehicles, not accounting for the effects of the Final 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 142 percent from 1970 to 1999, and approximately 166 percent from 1970 to 2011, as shown in Figure 4.1.1-1. For example, NO_X emissions, due mainly to light trucks and heavy-duty vehicles, decreased by 60 percent between 1970 and 2013, despite increases in VMT (EPA 2013a). Future trends show that changes in VMT 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 certain extent, with implementation of any of the action alternatives. MSAT emissions will likely decrease in the future because of recent EPA rules (EPA 2007). These rules limited the benzene content of gasoline beginning in 2011. They also limit exhaust emissions of hydrocarbons (many VOCs and MSATs are hydrocarbons) from passenger cars and light trucks when they are operated at cold temperatures. The cold-temperature standard was phased in from 2010 through 2015. EPA projects that these controls will substantially reduce emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde.

[12] Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule, 79 FR 23414 (April 28, 2014).

[13] Model year 1984 heavy-duty engines met standards of 10.7 grams per brake horsepower-hour (g/bhp-hr) NO_X and 0.6 g/bhp-hr PM; model year 2007 and later heavy-duty engines meet standards of 0.2 g/bhp-hr NO_X and 0.01 g/bhp-hr PM.

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



[a] Because CO emissions are generally about 10 times higher than emissions of NO_X, SO_X, and VOCs, and emissions of PM2.5 are about 10 times lower than emissions of NO_X, SO_X, and VOCs, the scales for CO and PM2.5 are proportionally adjusted to enable comparison of trends among pollutants.

[b] Apparent increases in NO_X and PM2.5 emissions in 2002 are due to a methodology change made by EPA in 2012 from the MOBILE6.2 model to the MOVES model to calculate emissions for years 2002 and later (EPA 2013b).

Sources: Davis et al. 2013, EPA 2011, EPA 2013a, EPA 2013b, EIA 2014a, IEC 2011.

VMT = vehicle miles traveled; VOCs = volatile organic compounds; NO_X = nitrogen oxides; CO = carbon monoxide;
PM2.5 = particulate matter with a diameter of 2.5 microns or less.

4.1.1.4 Conformity Regulations

The CAA prohibits a federal agency from engaging in or supporting an activity that does not "conform" to a State Implementation Plan (SIP) or Federal Implementation Plan after EPA has approved or promulgated it, or that would affect a state's compliance with the NAAQS.[14] The purpose of the conformity requirement is to ensure that federally sponsored or conducted activities do not interfere with meeting the emissions targets in SIPs, do not cause or contribute to new violations of the NAAQS, and do not impede the ability of a state to attain or maintain NAAQS or delay any interim milestones. EPA has issued two sets of regulations to implement the conformity requirements:

- The Transportation Conformity Rule (40 Code of Federal Regulations [CFR] part 51, Subpart T and part 93, Subpart A), which applies to transportation plans, programs, and projects funded or approved under Title 23 U.S.C. or Title 49 U.S.C., Chapter 53 (Public Transportation).

[14] 42 United States Code [U.S.C.] § 7506(c)(1)

- The General Conformity Rule (40 CFR part 51, Subpart W and part 93, Subpart B), which applies to all other federal actions not covered under transportation conformity. The General Conformity Rule establishes emissions thresholds for use in evaluating the conformity of an action that results in emissions increases. *See* 40 CFR 93.153(b). If the net increases of direct and indirect emissions are lower than these thresholds, then the action is presumed to conform and no further conformity evaluation is required. If the net increases of direct and indirect emissions exceed any of these thresholds, and the action is not otherwise exempt, 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 SIPs or to implement measures to mitigate air quality impacts.

The HD vehicle fuel efficiency standards and associated program activities are not funded or approved under Title 23 U.S.C. or Title 49 U.S.C., Chapter 53. Further, the standards are not a highway or transit project funded or approved by FHWA or the Federal Transit Administration. Accordingly, this action and associated program activities are not subject to the Transportation Conformity Rule. Instead, we evaluate the applicability of the General Conformity Rule. 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 originating in nonattainment or maintenance areas equaling or exceeding the rates specified in 40 CFR § 93.153(b)(1) and (2). As explained below, NHTSA's Final Action results in neither direct nor indirect emissions as defined at 40 CFR § 93.152.

The General Conformity Rule defines direct emissions as "those emissions 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 Final Action would set fuel efficiency standards for HD vehicles, it causes no direct emissions within the meaning of the General Conformity Rule. *See Department of Transportation v. Public Citizen*, 541 U.S. 752, 772 (2004) ("[T]he emissions from the Mexican trucks are not 'direct' because they will not occur at the same time or at the same place as the promulgation of the regulations.").

Indirect emissions under the General Conformity Rule are "those emissions of a criteria pollutant or its precursors (1) That are caused or initiated by the federal action and originate in the same nonattainment or maintenance area but occur at a different time or place as the action; (2) That are reasonably foreseeable; (3) That the agency can practically control; and (4) For which the agency has continuing program responsibility." 40 CFR § 93.152. Each element of the definition must be met to qualify as indirect emissions. NHTSA has determined that, for purposes of general conformity, emissions that may result from the fuel efficiency 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." 40 CFR § 93.152.

As the fuel efficiency improvement program uses performance-based standards, NHTSA cannot control the technologies vehicle manufacturers' use to improve the fuel efficiency of HD vehicles. Furthermore, NHTSA cannot control consumer purchasing and driving behavior (e.g., the rebound effect). For purposes of analyzing the environmental impacts of the Final Action under NEPA, NHTSA has made assumptions regarding the technologies manufacturers will install and how companies will react to increased fuel efficiency standards. Specifically, NHTSA's NEPA analysis predicts that increases in air toxic and criteria pollutants would occur in some nonattainment areas under certain alternatives based on the rebound effect. However, NHTSA's Final Action does not mandate specific manufacturer decisions or driver behavior, and NHTSA cannot control either. *See*, e.g., *Department of Transportation v. Public Citizen*, 541 U.S. 752, 772-73 (2004); *South Coast Air Quality Management District v. Federal Energy Regulatory Commission*, 621 F.3d 1085, 1101 (9th Cir. 2010).

NHTSA's NEPA analysis assumes a rebound effect, wherein the Final Action could create an incentive for additional vehicle use by reducing the relative cost of fuel. This rebound effect is an estimate of how NHTSA assumes some drivers and motor carriers will react to the rule and is important 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 (VMT) by drivers. Accordingly, changes in any emissions that result from NHTSA's standards are not changes the agency can practically control. Therefore, the Final Action would cause no indirect emissions under the General Conformity Rule, and a general conformity determination is not required.

4.1.2 Methodology

This section describes the approaches and methods that NHTSA used to estimate the impacts of the Final Action and alternatives, including an overview (Section 4.1.2.1), regional analysis (Section 4.1.2.2), timeframes for analysis (Section 4.1.2.3), treatment of incomplete or unavailable information (Section 4.1.2.4), allocation of estimated emissions to nonattainment areas (Sections 4.1.2.5 and 4.1.2.6), and estimates of health outcomes and monetized benefits (Section 4.1.2.7) .

4.1.2.1 Overview

To analyze air quality and human health impacts, NHTSA calculated the emissions of criteria pollutants and MSATs from HD vehicles 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 Section 2.4.1. In summary, the change in emissions resulting from each alternative is the sum of (1) changes in upstream emissions, which usually are reductions due to the decline in fuel consumption and, therefore, a lower volume of fuel production and distribution; (2) decreases (usually) in per-vehicle (downstream) emissions rates resulting from application of fuel efficiency technologies; and (3) the increase in vehicle (downstream) emissions resulting from added vehicle use due to the fuel-efficiency rebound effect.

As discussed in Chapter 2, the air quality results presented in this chapter, including impacts to human health, are based on a number of assumptions about the type and rate of emissions from the combustion of fossil fuels. In addition to tailpipe emissions, this analysis accounts for upstream emissions from the production and distribution of fuels. To estimate upstream emissions changes resulting from decreased downstream fuel consumption, the analysis uses a spreadsheet model developed by EPA and based on emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET) model (versions 1.8c and later developed by the U.S. Department of Energy [DOE] Argonne National Laboratory). The agencies modified or updated some of the GREET values to be consistent with EPA's National Emission Inventory and emission factors from MOVES. The spreadsheet model uses the decreased volumes of the fuels along with the emissions factors for the various fuel production and transport processes to estimate the net changes in upstream emissions as a result of fuel consumption changes.

4.1.2.2 Regional Analysis

Over the course of the development of recent CAFE EISs and the Phase 1 EIS, NHTSA received comments requesting that the agency consider the sub-national air quality impacts of these programs. NHTSA has included the following information about regional air quality impacts of the Final Action and alternatives in response to such comments and because the agency believes that such an analysis provides valuable information for the decisionmaker, state and local authorities, and the general 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 nationwide EIS, NHTSA believes a regional emissions analysis still provides valuable information and is feasible for the scope of this analysis.

To assess regional differences in the effects of the alternatives, NHTSA estimated net emissions changes for individual nonattainment and maintenance areas. The distribution of emissions is not uniform nationwide, and either increases or decreases in emissions can occur within individual nonattainment and maintenance areas. NHTSA focused on nonattainment and maintenance areas because these are the regions in which air quality problems have been greatest. NHTSA assessed only areas that are in nonattainment or maintenance for ozone or PM2.5 because these are the pollutants for which emissions from HD vehicles are of greatest concern. At present, there are no CO or NO_2 nonattainment areas. There are many areas designated as being in nonattainment for SO_2 or PM10. There are also maintenance areas for CO, NO_2, PM10, and SO_2. NHTSA did not quantify PM10 emissions separately from PM2.5 because almost all the PM in the exhaust from HD vehicles is PM2.5.[15] Appendix A provides emissions estimates for all nonattainment and maintenance areas for all criteria pollutants (except lead, as explained in Section 4.1.1.1.4). On-road motor vehicles are a minor contributor to SO_2 emissions (less than 0.56 percent of national 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 and maintenance areas. Emissions increases due to the rebound effect consist of higher emissions from HD vehicles operating on entire regional roadway networks, so that any emissions 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 Final Action and alternatives 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 Timeframes for Analysis

Ground-level concentrations of criteria and toxic air pollutants generally respond quickly to changes in emissions rates. The longest averaging period for measuring whether ambient concentrations of a

[15] In addition to exhaust PM2.5, the analysis included the brake wear and tire wear components of PM2.5.

pollutant comply with the NAAQS is 1 year.[16] 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, as follows.

- **2018:** A baseline/early forecast year; last year in which new HD vehicles are generally required to meet fuel efficiency standards that increase over the previous year, as set forth under NHTSA's Phase 1 EIS. (Phase 1 fuel efficiency standards remain the same for subsequent years until the Final Action takes effect.)
- **2025:** An early forecast year; by this point about half of HD vehicle VMT would be accounted for by vehicles that meet fuel efficiency standards as set forth under the Final Action.
- **2040:** A mid-term forecast year; by this point a large proportion of HD vehicle VMT would be accounted for by vehicles that meet fuel efficiency standards as set forth under the Final Action.
- **2050:** By 2050, almost all HD vehicles in operation would meet fuel efficiency standards as set forth under the Final Action, and changes in year-over-year impacts would be determined primarily by VMT growth rather than by MY 2021–2027 HD vehicles (MY 2018–2027 HD trailers) replacing older, less fuel-efficient HD 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.[17] 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 uncertain (and therefore may be incomplete or unavailable) include future emissions rates, vehicle manufacturers' decisions about vehicle technology and design, the mix of vehicle types and model years comprising the HD vehicle 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., emissions 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-

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[16] 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 PM2.5 NAAQS is based on the average of the daily 98th-percentile concentrations averaged over a 3-year period; and compliance with the annual PM2.5 NAAQS is based on the 3-year average of the weighted annual mean concentrations.

[17] *See* 40 CFR § 1502.22(b).

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 also result in health benefits, 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[18]

For each alternative, the Volpe and MOVES models provided national emissions 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 HD vehicle VMT data for all counties in the United States, consistent with EPA's National Emissions Inventory (NEI).[19] 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 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 and MOVES models.

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 emissions 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 estimate of county-level VMT allocation is constant over time, which introduces some uncertainty into the nonattainment-area-level VMT estimates for future years. Additional uncertainties that affect county-level exhaust emissions 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 inspection and maintenance programs, and fuel composition requirements. Because of these uncertainties, emissions in a particular nonattainment area may be overestimated or underestimated. The overall uncertainty increases as the projection period lengthens, such as for analysis years 2040 and 2050 compared with analysis years 2018 and 2025.

The geographic definitions of ozone and PM2.5 nonattainment areas that NHTSA uses in this document came from the current EPA Green Book Nonattainment Areas for Criteria Pollutants (EPA 2013e). 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 2013 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

[18] In Sections 4.1.2.5 and 4.1.2.6, where the term *nonattainment* is used, it includes both nonattainment areas and maintenance areas.

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

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 PM2.5 and their status/classification and general conformity threshold.

Table 4.1.2-1. Nonattainment and Maintenance Areas for Ozone and PM2.5

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Allegheny County, PA	PM2.5	Moderate	100
Allentown, PA	PM2.5	Maintenance	100
Allentown-Bethlehem-Easton, PA	Ozone	Marginal	50
Atlanta, GA	Ozone	Moderate	100
Baltimore, MD	Ozone	Moderate	50
Baton Rouge, LA	Ozone	Marginal	100
Birmingham, AL	PM2.5	Maintenance	100
Calaveras County, CA	Ozone	Marginal	100
Canton-Massillon, OH	PM2.5	Maintenance	100
Charleston, WV	PM2.5	Maintenance	100
Charlotte-Gastonia-Rock Hill, NC-SC	Ozone	Maintenance	100
Chicago-Naperville, IL-IN-WI	Ozone	Moderate	100
Chico (Butte County), CA	Ozone	Marginal	100
Chico, CA	PM2.5	Moderate	100
Cincinnati-Hamilton, OH-KY-IN	Ozone	Marginal	100
Cleveland, OH	PM2.5	Moderate	100
Cleveland-Akron-Lorain, OH	Ozone	Marginal	100
Cleveland-Akron-Lorain, OH	PM2.5	Maintenance	100
Columbus, OH	Ozone	Marginal	100
Dallas-Fort Worth, TX	Ozone	Moderate	100
Delaware County, PA	PM2.5	Moderate	100
Denver-Boulder-Greeley-Fort Collins-Loveland, CO	Ozone	Moderate	100
Detroit-Ann Arbor, MI	PM2.5	Maintenance	100
Dukes County, MA	Ozone	Marginal	50
Fairbanks, AK	PM2.5	Moderate	100
Greater Connecticut, CT	Ozone	Moderate	50
Harrisburg-Lebanon-Carlisle-York, PA	PM2.5	Maintenance	100
Houston-Galveston-Brazoria, TX	Ozone	Marginal	100
Imperial County, CA	Ozone	Moderate	100
Imperial County, CA	PM2.5	Moderate	100
Jamestown, NY	Ozone	Marginal	50
Johnstown, PA	PM2.5	Maintenance	100

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Kern County (Eastern Kern), CA	Ozone	Moderate	100
Klamath Falls, OR	PM2.5	Moderate	100
Knoxville, TN	Ozone	Maintenance	100
Knoxville-Sevierville-LaFollette, TN	PM2.5	Moderate	100
Lancaster, PA	Ozone	Marginal	50
Lancaster, PA	PM2.5	Maintenance	100
Lebanon County, PA	PM2.5	Moderate	100
Liberty-Clairton, PA	PM2.5	Moderate	100
Logan, UT-ID	PM2.5	Moderate	100
Los Angeles, CA	PM2.5	Serious	70
Los Angeles-San Bernardino Counties (Western Mojave), CA	Ozone	Severe-15	25
Los Angeles South Coast Air Basin, CA	Ozone	Extreme	10
Los Angeles South Coast Air Basin, CA	PM2.5	Moderate	100
Mariposa County, CA	Ozone	Moderate	100
Memphis, TN-MS-AR	Ozone	TN: Marginal	100
Memphis, TN-MS-AR	Ozone	MS, Maintenance	100
Milwaukee-Racine, WI	PM2.5	Maintenance	100
Morongo Band of Mission Indians, CA	Ozone	Serious	50
Nevada County (western part), CA	Ozone	Moderate	100
New York-N. New Jersey-Long Island, NY-NJ-CT	Ozone	Moderate	50
New York-N. New Jersey-Long Island, NY-NJ-CT	PM2.5	Maintenance	100
Nogales, AZ	PM2.5	Moderate	100
Oakridge, OR	PM2.5	Moderate	100
Pechanga Band of Luiseno Mission Indians of the Pechanga Reservation, CA	Ozone	Moderate	100
Philadelphia-Wilmington, PA-NJ-DE	PM2.5	Maintenance	100
Philadelphia-Wilmington-Atlantic City, PA-NJ-MD-DE	Ozone	Marginal	50
Phoenix-Mesa, AZ	Ozone	Moderate	100
Pittsburgh-Beaver Valley, PA	Ozone	Marginal	50
Pittsburgh-Beaver Valley, PA	PM2.5	Moderate	100
Plumas County, CA	PM2.5	Moderate	100
Provo, UT	PM2.5	Moderate	100
Reading, PA	Ozone	Marginal	50
Riverside County (Coachella Valley), CA	Ozone	Severe-15	25
Sacramento Metro, CA	Ozone	Severe-15	25
Sacramento Metro, CA	PM2.5	Moderate	100
Salt Lake City, UT	PM2.5	Moderate	100
San Diego County, CA	Ozone	Moderate	100
San Francisco Bay Area, CA	Ozone	Marginal	100
San Francisco Bay Area, CA	PM2.5	Moderate	100
San Joaquin Valley, CA	Ozone	Extreme	10

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
San Joaquin Valley, CA	PM2.5	Serious	70
San Luis Obispo (Eastern San Luis Obispo), CA	Ozone	Marginal	100
Seaford, DE	Ozone	Marginal	100
Seattle-Tacoma, WA	PM2.5	Maintenance	100
Sheboygan County, WI	Ozone	Marginal	100
St. Louis-St. Charles-Farmington, MO-IL	Ozone	Marginal	100
Steubenville-Weirton, OH-WV	PM2.5	Maintenance	100
Tuscan Buttes, CA	Ozone	Marginal	100
Upper Green River Basin Area, WY	Ozone	Marginal	100
Ventura County, CA	Ozone	Serious	50
Washington, DC-MD-VA	Ozone	Marginal	50
West Central Pinal County, AZ	PM2.5	Moderate	100
West Silver Valley, ID	PM2.5	Moderate	100
Yuba City-Marysville, CA	PM2.5	Maintenance	100

Notes:

[a] Pollutants for which the area is designated in nonattainment or maintenance as of 2016. For nonattainment areas, the status given is the severity classification. Where an area is nonattainment for more than one standard for the same pollutant, the more restrictive severity classification is shown.

[b] Emissions thresholds in tons/year. In ozone nonattainment areas the thresholds given are for the precursor pollutants VOC or NO_X; in PM2.5 nonattainment areas the thresholds represent primary PM2.5. Where an area is nonattainment for more than one standard for the same pollutant, the lowest applicable threshold is shown. Source: 40 CFR § 51.853. These thresholds are provided for information only; a general conformity determination is not required for the Final Action.

Source: EPA 2016b.

NO_X = nitrogen oxides; PM2.5 = particulate matter with a nominal aerodynamic diameter equal to or less than 2.5 microns; VOC = volatile organic compounds

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.[20] Emissions of pollutants at each stage are associated with expenditure of energy and with leakage or spillage and evaporation of fuel products. 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 and

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

the Phase 1 EIS. As noted below, NHTSA made a number of important assumptions for this analysis due to uncertainty over the accuracy of the allocation of upstream emissions.

To analyze the impacts of the alternatives on individual nonattainment areas, NHTSA allocated emissions 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 10 are in nonattainment areas. These 10 fields account for 15 percent of domestic production, or 3 percent of total crude-oil imports plus domestic production in 2009 (EIA 2009, 2014b, 2014c). Therefore, because relatively little extraction occurs in nonattainment areas, NHTSA did not account for emissions reductions from crude oil feedstock recovery in nonattainment areas.

  NHTSA assumed that little to no extraction of natural gas occurs in nonattainment areas. Of the top 50 highest producing natural gas fields in the United States, 8 are in nonattainment areas. These 8 fields account for 6 percent of total natural gas imports plus domestic gross withdrawals in 2009 (EIA 2009, 2014d, 2014e). Therefore, because relatively little extraction occurs in nonattainment areas, NHTSA did not account for emissions reductions from natural gas 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 emissions reductions from feedstock transportation within nonattainment areas.

Because NHTSA did not account for emissions changes from the first two upstream stages, the assumptions produce conservative estimates of emissions reductions in nonattainment areas (i.e., the estimates slightly underestimate the emissions 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 9 percent and 86 percent of all upstream emissions per unit of fuel produced and distributed (based on GREET version 1.8c). NHTSA used projected emissions data from the EPA 2011-based air quality modeling platform (EPA 2014d) to allocate reductions in nationwide total emissions from fuel refining to individual nonattainment areas. These EPA data were projected for 2018, 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.
- **TS&D**: NHTSA used data from the 2011-based EPA modeling platform (EPA 2014e) 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.

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 to several health outcomes and the monetized benefits associated with avoided health outcomes. Table 4.1.2-2 lists the health outcomes NHTSA quantified and monetized. 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 for each primary pollutant (NO_X, directly emitted PM2.5, and SO_2) and expressed as adverse health outcomes avoided or monetized health benefits gained per ton of reduced emissions. Each primary pollutant has a specific factor that is related to its quantifiable health impacts. 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.

Table 4.1.2-2. Human Health and Welfare Effects of PM2.5

Effects Quantified and Monetized	Effects Excluded from Quantification or Monetization [a]
Adult premature mortality	Chronic bronchitis (age >26)
Infant mortality	Emergency room visits for cardiovascular effects
Acute bronchitis (age 8-12)	Strokes and cerebrovascular disease (age 50–79)
Hospital admissions: respiratory (all ages) and cardiovascular (age >26)	Other respiratory effects (e.g., pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations)
Emergency room visits for asthma	Cardiovascular effects other than those listed
Non-fatal heart attacks (age >18)	Reproductive and developmental effects (e.g., low birth weight, preterm births)
Lower (age 7–14) and upper (age 9–11) respiratory symptoms	Cancer, mutagenicity, and genotoxicity effects
Minor restricted-activity days (age 18–65)	
Lost work days (age 18–65)	
Asthma exacerbations (asthmatics age 6–18)	

Notes:

[a] EPA excluded these effects because of insufficient confidence in available data or methods, or because current evidence is only suggestive of causality or there are other significant concerns over the strength of the association.

Source: EPA 2013f. *See* this source for more information related to the affected ages included in the analysis.

PM2.5 = particulate matter 2.5 micrometers or less; EPA = U.S. Environmental Protection Agency

In calculating the health impacts and monetized health benefits of emissions reductions, NHTSA estimated only the PM2.5-related human health impacts expected to result from reduced population exposure to atmospheric concentrations of PM2.5. Two other pollutants—NO_X and SO_2—are included in the analysis as precursor emissions that contribute to PM2.5 not emitted directly from a source, but instead formed by chemical reactions in the atmosphere (secondary PM2.5). As discussed further in Section 4.1.2.7.2, reductions in NO_X and VOC emissions would also reduce ozone formation and the health effects associated with ozone exposure, but there are no benefit-per-ton estimates for NO_X and VOCs because of the complexity of the atmospheric air chemistry and non-linearities associated with ozone formation. This analysis does not include any reductions in health impacts resulting from lower population exposure to other criteria air pollutants and air toxics because there are not enough data available to quantify these effects.

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 PM2.5 benefit-per-ton estimates apply to directly emitted PM2.5 or its precursors (NO_X and SO_2). NHTSA followed the benefit-per-ton technique used in EPA's PM2.5 NAAQS Regulatory Impact Analysis (RIA) (EPA 2013c), Ozone NAAQS RIA (EPA 2010a), Portland Cement National Emission Standards for Hazardous Air Pollutants RIA (EPA 2010b), and NO_2 NAAQS RIA (EPA 2010c), and most recently updated in EPA's Technical Support Document *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors* (EPA 2013f). Updates from the 2006 PM NAAQS RIA in the 2012 PM2.5 NAAQS RIA include no longer assuming a concentration threshold in the concentration-response function for the PM2.5-related health effects; using benefits derived from two major cohort studies of PM2.5 and mortality as the core benefits estimates; and baseline incidence rates for hospital admissions, emergency department visits, and asthma prevalence rates. Revised health endpoints, sensitivity analyses, new morbidity studies, and an updated median wage data were also included.

Table 4.1.2-2 lists the quantified PM2.5-related benefits captured in those benefit-per-ton estimates, and potential PM2.5-related benefits that were not quantified in this analysis. The benefits estimates use the concentration-response functions[21] 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 Document *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors* (EPA 2013f). Readers can also consult Fann et al. (2009) for a detailed description of the benefit-per-ton methodology.[22]

As described in the documentation cited above for the benefit-per-ton estimates, 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 PM2.5

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[21] 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 period).

[22] 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 its value of a statistical life (VSL) to equal $6.3 million (in year 2000 dollars), or $8.4 million (in year 2012 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 2014b).

benefits is, therefore, based on the total direct PM2.5 and PM2.5-related precursor emissions controlled by sector and multiplied by this per-ton value.

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 (Krewski et al. 2009) and the Harvard Six Cities cohort (Lepeule et al. 2012). 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 both studies to be equal in terms of strengths and weaknesses and the quality of results. According to EPA, both studies should be used to generate benefits estimates (EPA 2013f). Throughout the discussion of mortality in this section, the mortality rates calculated from each of these studies are presented side by side.

For both studies, the benefits of mortality reductions do not occur in the year of analysis. Instead, EPA's methodology assumes that there is a cessation lag—that is, the benefits are distributed across 20 years following the year of exposure (the emissions analysis year). Because of this, the monetized value of the reduced mortality depends on the discount rate applied to future-year benefits from the cessation lag. To account for this factor, the monetized benefits of reduced mortality are presented using 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 is approximately 10 percent smaller under the 7 percent discount rate than under the 3 percent discount rate.

The benefits-per-ton estimates used in this analysis are based on the above mortality health outcome factors, combined with data on the monetized value of each health outcome. These monetized values are expressed through several metrics; premature mortality is monetized using DOT's estimate of the value of statistical life (VSL) (DOT 2015). Morbidity impacts are measured either through willingness-to-pay or cost-of-illness measures that account for either desire to avoid the health outcome or actual medical costs and wage lost associated with a specific case.

Because the VSL values used by DOT and EPA are different, NHTSA adjusted EPA's benefit-per-ton values to reflect the DOT VSL of $9.2 million (in 2013 dollars) rather than the EPA VSL of $8.4 million (in 2012 dollars).[23] (The VSL of $8.4 million is an update by EPA of the value adopted in the 2014 Update of the Guidelines for Preparing Economic Analyses [EPA 2014e] and estimated at $7.9 million in 2008 dollars.) The discrepancy between the DOT and EPA estimates is not unexpected, because no single dollar value has been accepted in the academic community or across the Federal Government. Note that because the benefits-per-ton data combine mortality and morbidity benefits, the adjustment for DOT VSL is applied to both mortality and morbidity components of the data. Because VSL represents only mortality, this adjustment likely results in the analysis underestimating the total benefits per ton. However, because mortality accounts for most of total monetized health benefits, any underestimation is likely to be small.

Table 4.1.2-3 lists the dollar-per-ton estimates used in this analysis. Table 4.1.2-4 lists the valuation metrics for the mortality and morbidity endpoints.

[23] 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 2013 values in accordance with changes in prices and incomes over the past several years.

Table 4.1.2-3. Benefit-per-ton Values (in 2013 dollars) Derived for PM-related Mortality and Morbidity, Adjusted to Reflect DOT's Value of Statistical Life[a]

Year[b]	Upstream Emissions (Data for Refineries Sector)			Downstream Emissions (Data for On-Road Sources Sector)		
	Direct PM2.5	SO_2	NO_X	Direct PM2.5	SO_2	NO_X
3-Percent Discount Rate						
Mortality[c] and Morbidity – Krewski et al. (2009)						
2018	$374,000	$80,000	$8,000	$433,000	$23,000	$9,000
2025	$433,000	$92,000	$9,000	$491,000	$27,000	$10,000
2040	$507,000	$109,000	$10,000	$578,000	$33,000	$11,000
2050	$507,000	$109,000	$10,000	$578,000	$33,000	$11,000
Mortality[c] and Morbidity – Lepeule et al. (2012)						
2018	$854,000	$181,000	$18,000	$977,000	$53,000	$20,000
2025	$971,000	$211,000	$20,000	$1,112,000	$61,000	$22,000
2040	$1,132,000	$242,000	$24,000	$1,261,000	$74,000	$26,000
2050	$1,132,000	$242,000	$24,000	$1,261,000	$74,000	$26,000
7-Percent Discount Rate						
Mortality[c] and Morbidity – Krewski et al. (2009)						
2018	$339,000	$73,000	$7,000	$392,000	$21,000	$8,000
2025	$386,000	$83,000	$8,000	$445,000	$25,000	$9,000
2040	$454,000	$97,000	$9,000	$518,000	$29,000	$10,000
2050	$454,000	$97,000	$9,000	$518,000	$29,000	$10,000
Mortality[c] and Morbidity – Lepeule et al. (2012)						
2018	$772,000	$158,000	$16,000	$883,000	$47,000	$18,000
2025	$878,000	$187,000	$19,000	$1,006,000	$55,000	$20,000
2040	$1,020,000	$218,000	$22,000	$1,173,000	$66,000	$24,000
2050	$1,020,000	$218,000	$22,000	$1,173,000	$66,000	$24,000

Notes:

[a] The benefits-per-ton estimates in this table are based on EPA estimates of premature mortality by Krewski et al. (2009) and Lepeule et al. (2012), and a suite of morbidity endpoints (*see* Table 4.1.2-2). Benefits for two sectors (on-road mobile source and refineries) of the 17 sectors analyzed in EPA 2013f. Values are shown in 2013 dollars.

[b] Benefit-per-ton values were estimated for 2016, 2020, 2025, and 2030. For 2018 and 2035 (not reported in table), values were either interpolated or extrapolated based on the growth between 2016 and 2030. For 2040 and 2050, values were held constant from 2035 values because of the high level of uncertainty in projections to 2040 and 2050. All values have been rounded.

[c] For age under 25 or age over 30.

Source: EPA 2013f.

PM = particulate matter; NO_X = nitrogen oxides; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns;
SO_2 = sulfur dioxide

Table 4.1.2-4. Valuation Metrics for Mortality and Morbidity Endpoints (in 2013 dollars)

Health Outcome	Valuation Method	Valuation[a]
Premature Mortality		
Premature Mortality	DOT Mean VSL	$10,600,000
Chronic Illness		
Myocardial Infarctions, Non-fatal	Medical costs over 5 years; varies by age and discount rate.	Varies from $110,000 to $230,000, depending on age and discount rate
Hospital Admissions		
Respiratory, Age 65+	COI: Medical Costs + Wage Lost	$41,000
Chronic Lung Disease, Ages 18–64	COI: Medical Costs + Wage Lost	$24,000
Cardiovascular	COI: Medical Costs + Wage Lost (18–64) COI: Medical Costs + Wage Lost (65–99)	$48,000 $47,000
Emergency Room Visits		
Asthma	COI: 2 Studies	$490
Other Health Endpoints		
Acute Bronchitis	WTP: 6 Day Illness, CV Studies	$540
Upper Respiratory Symptoms	WTP: 1 Day, CV Studies	$37
Lower Respiratory Symptoms	WTP: 1 Day, CV Studies	$24
Asthma Exacerbation	WTP: Bad Asthma Day	$65
Work Loss Days	Median Daily Wage, County-Specific	Variable (U.S. Median = $170)
Minor Restricted Activity Days	WTP: 1 Day, CV Studies	$77

Notes:

[a] Central Estimate of Value Per Statistical Incidence. Table 5-9 in EPA 2013f presented VSLs for the year 1990, 2000, and 2020 income levels. The valuation presented in this table was interpolated for the year 2013 and are presented here in 2013 dollars. Dollar amounts for each valuation method were extracted by EPA from BenMAP and were presented in 2010 dollars in EPA 2013f.

Source: EPA 2013f.

COI = cost of illness; CV = contingent valuation; DOT = Department of Transportation; VSL = value of statistical life; WTP = willingness to pay

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 incomes. 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 (PM2.5). Emissions 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 Final Action and alternatives. Because the atmospheric chemistry related to ambient concentrations of PM2.5, 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 impacts on human health and welfare. This modeling provides insight into the uncertainties associated with the use of benefit-per-ton estimates. Appendix D provides the results of photochemical air quality modeling for the EIS.

- NHTSA assumed that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because PM2.5 produced via transported precursors emitted from stationary sources might differ significantly from direct PM2.5 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 PM2.5, 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 the following: 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 overestimate 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 non-linearities 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.

Because of these uncertainties it is not possible to draw conclusions about whether the benefit-per-ton values are underestimated or overestimated. The RIA for the 2012 PM2.5 NAAQS (EPA 2013c) provides more information about the overall uncertainty in the estimates of the benefits of reducing PM2.5 emissions.

4.1.2.7.3 Quantified Health Impacts

Table 4.1.2-5 lists the incidence-per-ton estimates for select PM-related health impacts—mortality and four major morbidity outcomes (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 these values for the 2018 and 2025 analysis years (*see* Section 4.1.2.3). NHTSA applied the values for 2030 to estimate impacts in 2040 and 2050.

Table 4.1.2-5. Incidence-per-ton Values for Health Outcomes

Outcome and Year[a]	Upstream Emissions (Data for Refineries Sector)			Downstream Emissions (Data for On-Road Sources Sector)		
	Direct PM2.5	SO_2	NO_X	Direct PM2.5	SO_2	NO_X
Premature Mortality – Krewski et al. (2009)						
2016	0.027000	0.00770	0.00076	0.042000	0.00220	0.00085
2018	0.032500	0.00785	0.00078	0.042500	0.00225	0.00086
2020	0.038000	0.00800	0.00079	0.043000	0.00230	0.00087
2025	0.040000	0.00860	0.00085	0.047000	0.00260	0.00093
2030	0.044000	0.00950	0.00092	0.051000	0.00280	0.00100
Premature Mortality – Lepeule et al. (2012)						
2016	0.062000	0.01700	0.00170	0.094000	0.00500	0.00190
2018	0.073500	0.01750	0.00175	0.096000	0.00515	0.00195
2020	0.085000	0.01800	0.00180	0.098000	0.00530	0.00200
2025	0.091000	0.02000	0.00190	0.110000	0.00580	0.00210
2030	0.099000	0.02100	0.00210	0.110000	0.00640	0.00230
Acute Bronchitis						
2016	0.042000	0.01300	0.00130	0.067000	0.00400	0.00140
2018	0.052000	0.01300	0.00130	0.068000	0.00405	0.00140
2020	0.062000	0.01300	0.00130	0.069000	0.00410	0.00140
2025	0.065000	0.01400	0.00140	0.072000	0.00440	0.00140
2030	0.066000	0.01400	0.00140	0.075000	0.00460	0.00150
Work Loss Days						
2016	3.80000	1.10000	0.11000	5.90000	0.32000	0.12000
2018	4.55000	1.10000	0.11000	6.00000	0.33000	0.12000
2020	5.30000	1.10000	0.11000	6.10000	0.34000	0.12000
2025	5.30000	1.20000	0.11000	6.20000	0.35000	0.12000
2030	5.40000	1.20000	0.12000	6.40000	0.36000	0.12000
Emergency Room Visits – Respiratory						
2016	0.015000	0.00410	0.00042	0.024000	0.00110	0.00049
2018	0.017500	0.00415	0.00043	0.024500	0.00115	0.00050
2020	0.020000	0.00420	0.00043	0.025000	0.00120	0.00050
2025	0.020000	0.00430	0.00044	0.026000	0.00120	0.00051
2030	0.021000	0.00450	0.00046	0.026000	0.00130	0.00053

Notes:

[a] EPA estimated benefit-per-ton values for 2016, 2020, 2025, and 2030. For 2018, values were interpolated from trends shown in EPA 2013f. For 2040 and 2050 the EPA values for 2030 were used.

Source: EPA 2013f.

EPA = U.S. Environmental Protection Agency; NO_X = nitrogen oxides; PM2.5 = particulate matter with an aerodynamic diameter equal to or less than 2.5 microns; SO_2 = sulfur dioxide

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 emissions regulations under the CAA. EPA projects that these emissions will continue to decline. Future trends show that changes in VMT 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, EPA 2012c). This general trend will continue, to a certain extent, with implementation of any of the action alternatives.

The analysis in this section shows that the action alternatives result in different levels of emissions from HD vehicles when measured against projected trends under the No Action Alternative. These reductions or increases in emissions vary by pollutant, calendar year, and action alternative. The more stringent action alternatives generally would result in greater emissions reductions compared to the No Action Alternative. Alternative 4 is an exception for some pollutants and years because some of its provisions are less stringent than those of Alternative 3, as discussed in Section 2.2.

This section examines the direct and indirect impacts on air quality associated with the alternatives.[24] Section 4.2.2 examines cumulative air quality impacts of the alternatives.[25] Using the assumptions discussed in Section 2.3, this chapter presents direct and indirect impacts and cumulative air quality impacts to show a complete range of results.

The tables and figures in Section 4.2.1 and its subsections present the projected direct and indirect impacts of the 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 under Alternatives 1 through 5 in more detail.

4.2.1.1.1 Criteria Pollutants Overview

Table 4.2.1-1 summarizes the total upstream and downstream[26] national emissions from HD vehicles by alternative for each of the criteria pollutants and analysis years. Figure 4.2.1-1 illustrates this

[24] As explained in Chapter 2, the analysis of direct and indirect impacts compares action alternatives with a No Action Alternative that generally reflects a small forecast increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond, due to market-based incentives for improving fuel efficiency. By including these market-based improvements in the No Action Alternative, this analysis attempts to isolate the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to the rule, and not attributable to reasonably foreseeable future actions by manufacturers.

[25] As explained in Chapter 2, the cumulative impacts analysis compares the same action alternatives with a No Action Alternative that generally assumes no increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond (i.e., no increase beyond the 2014-2018 Phase 1 HD standards). In other words, this baseline does not take into account market-based incentives for improving fuel efficiency. By comparing the action alternatives to this baseline, the cumulative impacts analysis reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 and the direct and indirect impacts of Phase 2 HD standards associated with each action alternative.

[26] Downstream emissions do not include evaporative emissions from vehicle fuel systems due to modeling limitations.

information for 2040, the forecast year by which a large proportion of HD vehicle VMT would be accounted for by vehicles that meet standards as set forth under the Final Action.

Table 4.2.1-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
2018	1,755,602	1,755,683	1,755,669	1,755,689	1,755,706
2025	1,381,930	1,374,076	1,368,799	1,358,075	1,351,712
2040	1,258,030	1,231,146	1,207,915	1,185,953	1,172,921
2050	1,433,472	1,401,314	1,372,897	1,347,873	1,332,893
Nitrogen oxides (NO_X)					
2018	1,839,037	1,838,795	1,838,657	1,838,649	1,838,480
2025	1,065,302	1,054,972	1,043,547	1,032,988	1,022,201
2040	781,517	748,440	692,418	677,516	651,318
2050	870,456	831,293	762,411	746,849	716,200
Particulate matter (PM2.5)					
2018	86,453	86,422	86,411	86,407	86,399
2025	51,528	51,048	50,494	50,458	49,929
2040	39,540	38,072	35,366	36,016	34,519
2050	44,030	42,308	39,001	39,863	38,096
Sulfur dioxide (SO_2)					
2018	113,776	113,629	113,559	113,528	113,481
2025	118,954	116,312	113,109	112,544	109,422
2040	132,219	124,168	109,222	113,065	104,600
2050	146,781	137,365	119,180	124,303	114,367
Volatile organic compounds (VOC)					
2018	253,185	252,969	252,901	252,851	252,795
2025	179,452	177,101	174,513	174,502	172,298
2040	155,338	149,139	137,745	141,503	135,479
2050	170,785	163,686	150,041	154,845	147,844

Figure 4.2.1-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2040 by Alternative, Direct and Indirect Impacts

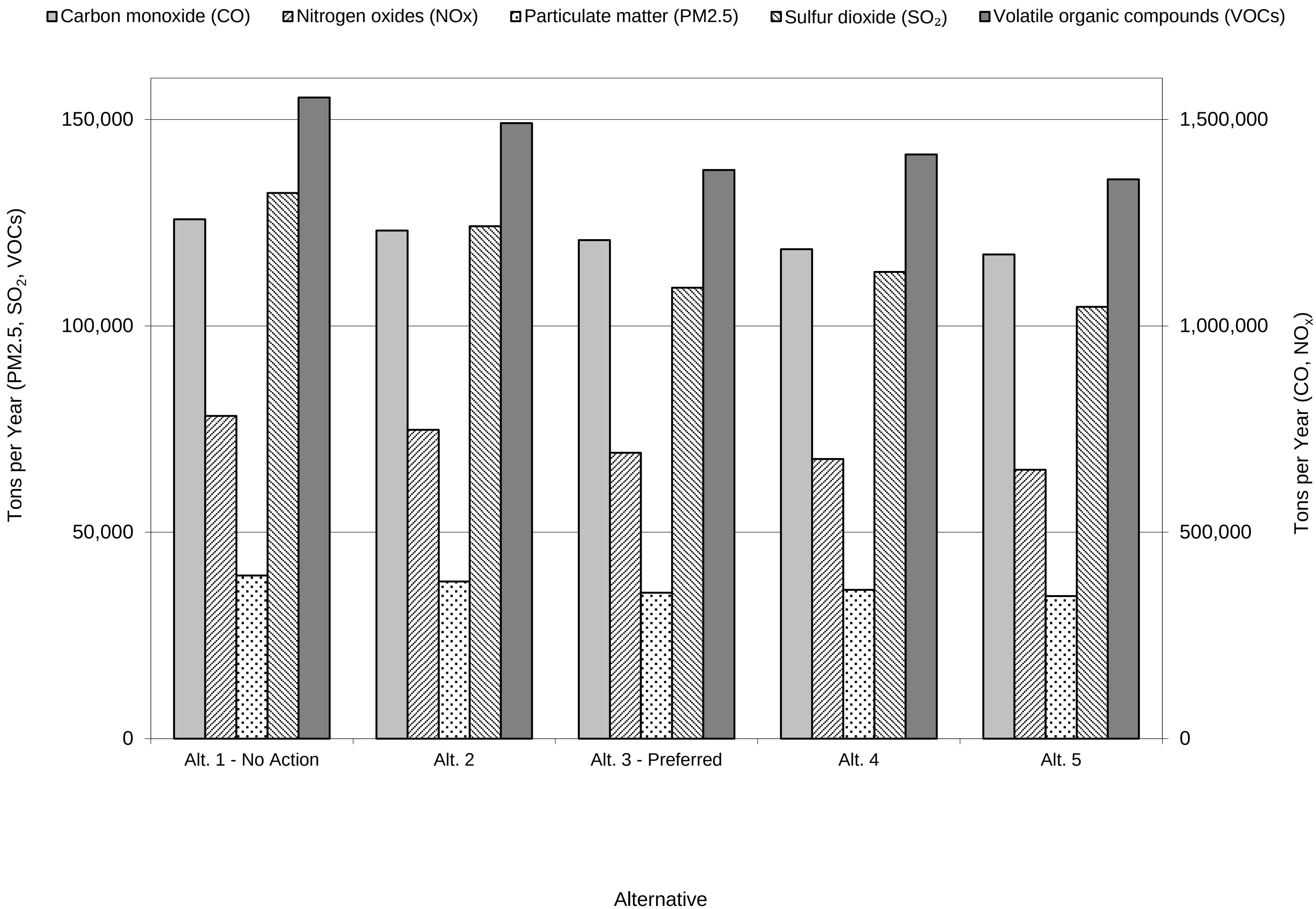
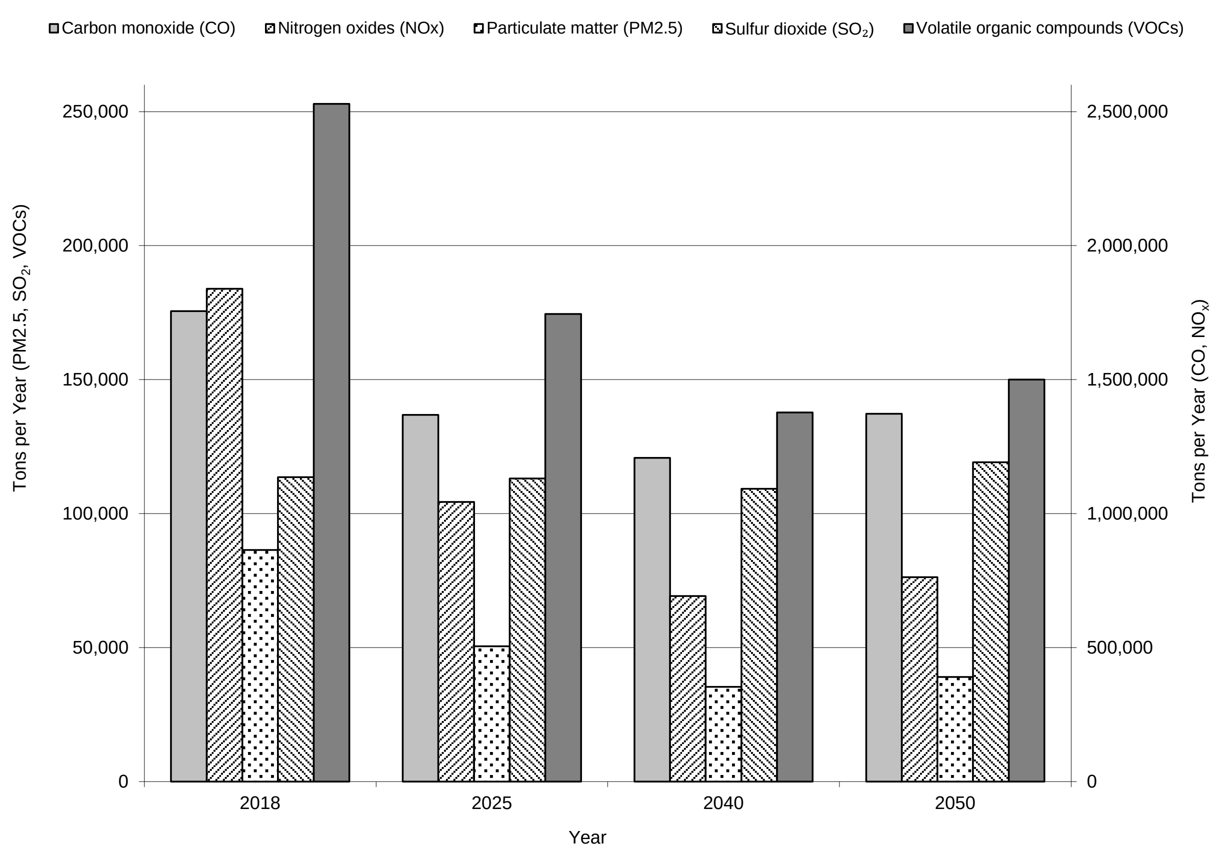


Figure 4.2.1-2 summarizes the changes over time in total national emissions of criteria pollutants from HD vehicles under the Preferred Alternative. Figure 4.2.1-2 shows a consistent trend among the criteria pollutants. Emissions of CO, NO_X, PM2.5, and VOCs would decrease due to the EPA emissions standards (*see* Section 4.1), despite a growth in total VMT from 2018 to 2040, but increase from 2040 to 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.1-1 and Figure 4.2.1-2). (Note that continued growth in VMT is projected to occur under all alternatives).

Figure 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Direct and Indirect Impacts



Emissions of SO_2 under all alternatives are predicted to increase from 2018 to 2050 because declines due to gains in new HD vehicle fuel efficiency are more than offset by continuing growth in VMT. The timing of the increases between 2018 and 2050 varies by alternative (Table 4.2.1-1). EPA regulates vehicle SO_2 emissions by limiting the concentration of sulfur in fuel and has not established tailpipe emissions standards for SO_2. As a result, SO_2 emissions vary only with total fuel consumption. Under the No Action Alternative, which assumes neither NHTSA nor EPA promulgate Phase 2 standards, total fuel consumption rises as VMT grows, and SO_2 emissions increase continuously from 2018 to 2050. Alternative 2 is not sufficiently stringent for fuel savings to offset VMT growth, so SO_2 emissions increase continuously from 2018 to 2050 under Alternative 2 as well. Under the Preferred Alternative and Alternative 5, SO_2 emissions decrease from 2018 to 2040 as the proportion of all vehicles that meets the Phase 2 standards increases, before emissions increase again by 2050 due to continued VMT growth. Under Alternative 4, SO_2 emissions decrease from 2018 to 2025 but then increase from 2025 to 2050, because some provisions of Alternative 4 are less stringent than those of Alternative 3, as discussed in Section 2.2.

Total emissions are made up of six components, consisting of two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the three vehicle classes covered by the rule: Classes 2b–3 HD pickups and vans, Classes 3–8 vocational vehicles, and Classes 7–8 tractor-trailers (combination units). (Emissions associated with the tractor-trailer classes include effects of the trailer standards.) To show the relationship among these six components for criteria pollutants, Table 4.2.1-2 breaks down the total emissions of criteria pollutants by component for calendar year 2040.

Table 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2040 from U.S. HD Vehicles, by Vehicle Type and Alternative, Direct and Indirect Impacts

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
Classes 2b–3 Work Trucks Tailpipe	282,690	284,549	286,274	286,344	287,084
Classes 2b–3 Work Trucks Upstream	11,058	10,432	9,852	9,832	9,587
Classes 3–8 Vocational Vehicles Tailpipe	676,690	676,483	676,365	676,415	676,331
Classes 3–8 Vocational Vehicles Upstream	15,610	14,459	13,241	13,633	12,875
Classes 7–8 Combination Unit Tailpipe	215,781	192,309	176,856	152,372	143,991
Classes 7–8 Combination Unit Upstream	56,201	52,914	45,328	47,357	43,053
Total	1,258,030	1,231,146	1,207,915	1,185,953	1,172,921
Nitrogen oxides (NO_X)					
Classes 2b–3 Work Trucks Tailpipe	41,205	41,478	41,663	41,675	41,727
Classes 2b–3 Work Trucks Upstream	27,047	25,509	24,094	24,046	23,447
Classes 3–8 Vocational Vehicles Tailpipe	106,893	106,323	106,046	106,323	106,006
Classes 3–8 Vocational Vehicles Upstream	38,190	35,376	32,395	33,355	31,500
Classes 7–8 Combination Unit Tailpipe	430,875	410,479	377,479	356,418	343,453
Classes 7–8 Combination Unit Upstream	137,306	129,275	110,741	115,700	105,184
Total	781,517	748,440	692,418	677,516	651,318
Particulate matter (PM2.5)					
Classes 2b–3 Work Trucks Tailpipe	1,934	1,948	1,959	1,959	1,963
Classes 2b–3 Work Trucks Upstream	2,273	2,144	2,024	2,020	1,969
Classes 3–8 Vocational Vehicles Tailpipe	4,089	4,084	4,084	4,087	4,083
Classes 3–8 Vocational Vehicles Upstream	4,379	4,062	3,720	3,830	3,618
Classes 7–8 Combination Unit Tailpipe	11,950	11,792	11,551	11,553	11,461
Classes 7–8 Combination Unit Upstream	14,914	14,042	12,029	12,568	11,425
Total	39,540	38,072	35,366	36,016	34,519
Sulfur dioxide (SO_2)					
Classes 2b–3 Work Trucks Tailpipe	576	580	583	583	584
Classes 2b–3 Work Trucks Upstream	16,981	16,014	15,123	15,094	14,711
Classes 3–8 Vocational Vehicles Tailpipe	1,081	1,003	918	946	893

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Classes 3–8 Vocational Vehicles Upstream	23,811	22,052	20,194	20,792	19,636
Classes 7–8 Combination Unit Tailpipe	3,624	3,411	2,924	3,059	2,783
Classes 7–8 Combination Unit Upstream	86,147	81,108	69,479	72,590	65,993
Total	132,219	124,168	109,222	113,065	104,600
Volatile organic compounds (VOC)					
Classes 2b–3 Work Trucks Tailpipe	12,576	12,661	12,729	12,733	12,758
Classes 2b–3 Work Trucks Upstream	31,345	29,552	27,890	27,838	27,150
Classes 3–8 Vocational Vehicles Tailpipe	21,345	20,800	20,050	20,303	19,838
Classes 3–8 Vocational Vehicles Upstream	25,466	23,971	21,956	22,615	21,390
Classes 7–8 Combination Unit Tailpipe	27,741	27,447	25,387	26,952	26,103
Classes 7–8 Combination Unit Upstream	36,864	34,708	29,732	31,063	28,240
Total	155,338	149,139	137,745	141,503	135,479

Table 4.2.1-3 lists the net changes in nationwide criteria pollutant emissions from HD vehicles for each action alternative for each criteria pollutant and analysis year compared to the No Action Alternative in the same year. Figure 4.2.1-3 shows these changes in percentages for 2040. As a general trend, total emissions of each pollutant in a given year decrease from Alternative 2 through Alternative 5, depending on the stringency of the alternative. However, the magnitudes of the declines in total emissions are not consistent across all pollutants, and there are some increases for CO in the short term, which reflects the complex interactions between tailpipe emissions rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the standards, upstream emissions rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and increases in VMT. Instances where downstream (tailpipe) emissions are predicted to increase[27] (on a per-VMT basis) in the action alternatives are attributable to shifts in modeled technology adoption from the baseline. Tables 4.2.1-1 and 4.2.1-3 show that total emissions of all criteria pollutants in a given year decrease steadily from Alternative 1 through Alternative 5 (except that CO emissions increase slightly from the Preferred Alternative to Alternative 4 and Alternative 5 in 2018, and emissions of PM2.5, SO_2, and VOCs increase slightly from the Preferred Alternative to Alternative 4 in 2040 and 2050).

Under each action alternative compared to the No Action Alternative, the greatest relative reductions in emissions among the criteria pollutants occur for NO_X and SO_2, for which emissions decrease by as much as 22 percent by 2050 compared to the No Action Alternative (*see* Table 4.2.1-1). Percentage reductions in emissions of CO, PM2.5, and VOCs compared to the No Action Alternative are less.

The differences in national emissions of criteria air pollutants among the action alternatives compared to the No Action Alternative range from less than 1 percent to 22 percent due to the interactions of the multiple factors described above. The smaller differences are not expected to lead to measurable changes in concentrations of criteria pollutants in the ambient air. The larger differences in emissions could lead to changes in ambient pollutant concentrations.

[27] Criteria pollutant emissions do not increase above the vehicle emissions standards but rather increase within the allowable "headroom" of the standard.

Table 4.2.1-3. Nationwide Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b]

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
2018	0	81	67	86	103
2025	0	-7,854	-13,131	-23,855	-30,218
2040	0	-26,884	-50,115	-72,077	-85,109
2050	0	-32,159	-60,575	-85,600	-100,579
Nitrogen oxides (NO_X)					
2018	0	-243	-381	-388	-557
2025	0	-10,329	-21,754	-32,314	-43,100
2040	0	-33,077	-89,098	-104,000	-130,199
2050	0	-39,163	-108,045	-123,607	-154,256
Particulate matter (PM2.5)					
2018	0	-31	-42	-46	-54
2025	0	-480	-1,034	-1,070	-1,598
2040	0	-1,469	-4,174	-3,524	-5,022
2050	0	-1,723	-5,029	-4,167	-5,934
Sulfur dioxide (SO_2)					
2018	0	-147	-217	-248	-295
2025	0	-2,642	-5,846	-6,410	-9,532
2040	0	-8,051	-22,997	-19,154	-27,620
2050	0	-9,416	-27,602	-22,478	-32,414
Volatile organic compounds (VOC)					
2018	0	-216	-283	-333	-390
2025	0	-2,351	-4,938	-4,950	-7,154
2040	0	-6,199	-17,593	-13,834	-19,859
2050	0	-7,099	-20,744	-15,940	-22,941

Notes:

[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.

Figure 4.2.1-3 (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. HD Vehicles for 2040 by Action Alternative Compared to the No Action Alternative, Direct and Indirect Impacts

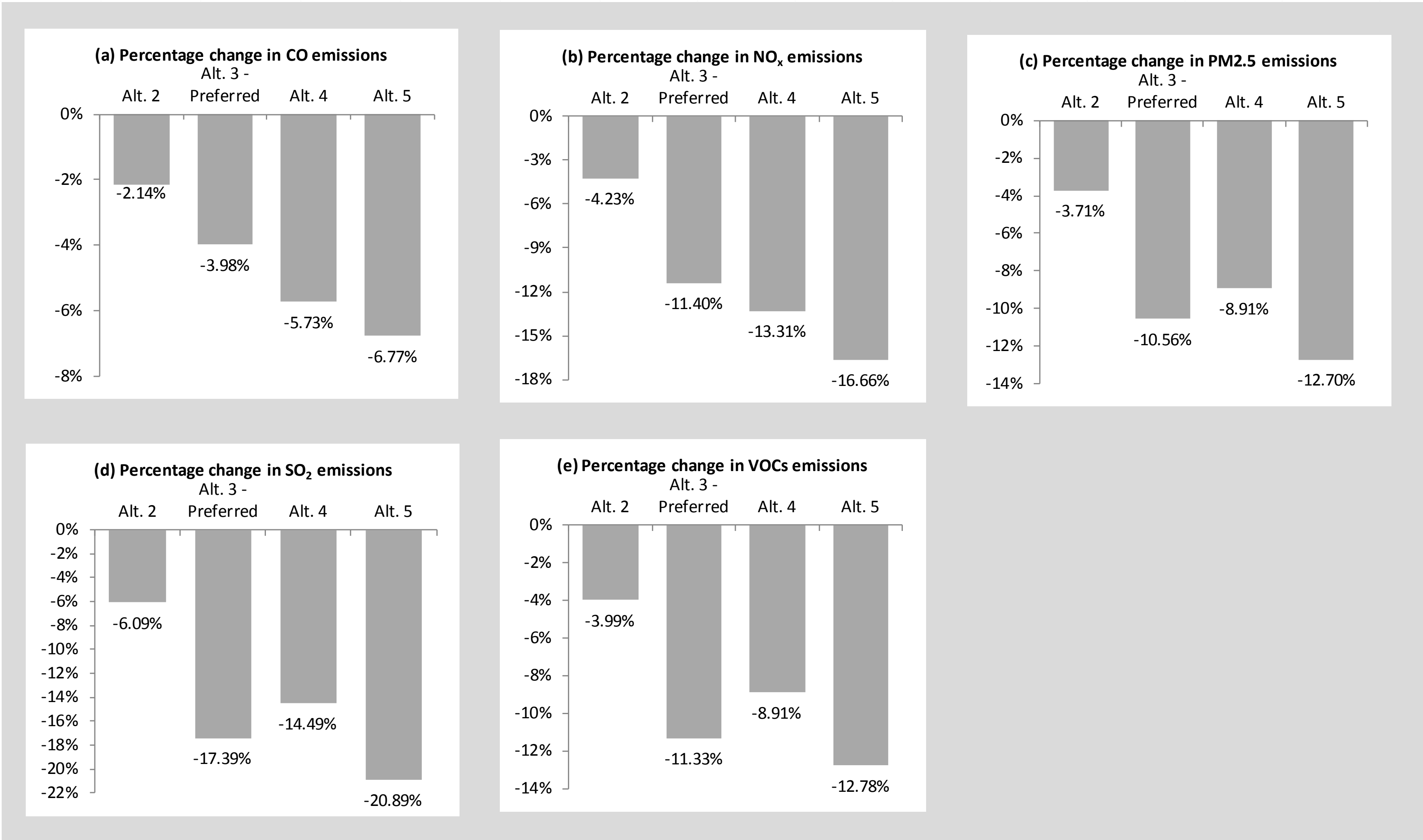


Table 4.2.1-4 summarizes the criteria air pollutant analysis results by nonattainment area. Tables in Appendix A list the emissions changes for each nonattainment area. For CO, Appendix A indicates that most nonattainment areas would experience increases in emissions in 2018 under all the action alternatives, but most would experience decreases in emissions in 2025, 2040, and 2050 under all the action alternatives. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions across all alternatives and years.

Table 4.2.1-4. Maximum Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts

Criteria Pollutant	Maximum Increase/Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area (NAAQS Standard[s])
Carbon monoxide (CO)	Maximum Increase	11	2018	Alt. 5	New York, NY-NJ-CT [PM 2.5 (2006 24-hour)]
	Maximum Decrease	-4,175	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Nitrogen oxides (NO_X)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-5,078	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Particulate matter (PM2.5)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-288	2050	Alt. 5	Baton Rouge, LA [Ozone (2008 8-hour)]
Sulfur dioxide (SO_2)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-1,502	2050	Alt. 5	Marshall, WV [SO_2 (2010 1-hour)]
Volatile organic compounds (VOC)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-483	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]

4.2.1.1.2 Toxic Air Pollutants Overview

Table 4.2.1-5 summarizes the total upstream and downstream[28] emissions of toxic air pollutants from HD vehicles by alternative for each of the toxic air pollutants and analysis years. The trends for toxic air pollutant emissions across the alternatives generally show decreases for the same reasons as for criteria pollutants (*see* Section 4.2.1.1.1). These tables show that emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde generally remain the same or decrease from Alternative 1 to Alternative 5. Where increases occur they are small. Emissions under Alternative 4 are slightly greater than under Alternative 3 for most pollutants and years for the same reasons as for the criteria pollutants (*see* Sections 2.2 and 4.2.1.1.1). 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 efficiency requirements.

[28] Downstream emissions do not include evaporative emissions from vehicle fuel systems due to modeling limitations.

Table 4.2.1-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
2018	5,510	5,510	5,510	5,510	5,510
2025	3,048	3,047	3,042	3,043	3,040
2040	2,107	2,100	2,075	2,088	2,082
2050	2,338	2,330	2,301	2,316	2,309
Acrolein					
2018	916	916	916	916	916
2025	463	463	463	464	464
2040	279	280	277	282	281
2050	314	314	311	316	315
Benzene					
2018	2,682	2,681	2,680	2,680	2,680
2025	1,838	1,828	1,813	1,812	1,798
2040	1,499	1,466	1,399	1,422	1,385
2050	1,658	1,620	1,540	1,567	1,526
1,3-Butadiene					
2018	508	508	508	508	508
2025	245	245	245	247	247
2040	119	122	119	125	125
2050	134	136	133	140	139
Diesel particulate matter (DPM)					
2018	124,407	124,375	124,361	124,358	124,349
2025	92,050	91,522	90,873	90,818	90,147
2040	86,758	85,055	81,719	82,569	80,672
2050	97,067	95,064	90,980	92,104	89,869
Formaldehyde					
2018	12,898	12,898	12,898	12,898	12,898
2025	7,818	7,797	7,775	7,755	7,736
2040	6,071	5,998	5,899	5,878	5,833
2050	6,828	6,742	6,619	6,600	6,548

Figure 4.2.1-4 shows toxic air pollutant emissions for each alternative in 2040, the forecast year by which a large proportion of HD vehicle VMT would be accounted for by vehicles that meet standards as set forth under the rulemaking.

Figure 4.2.1-4. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2040 by Alternative, Direct and Indirect Impacts

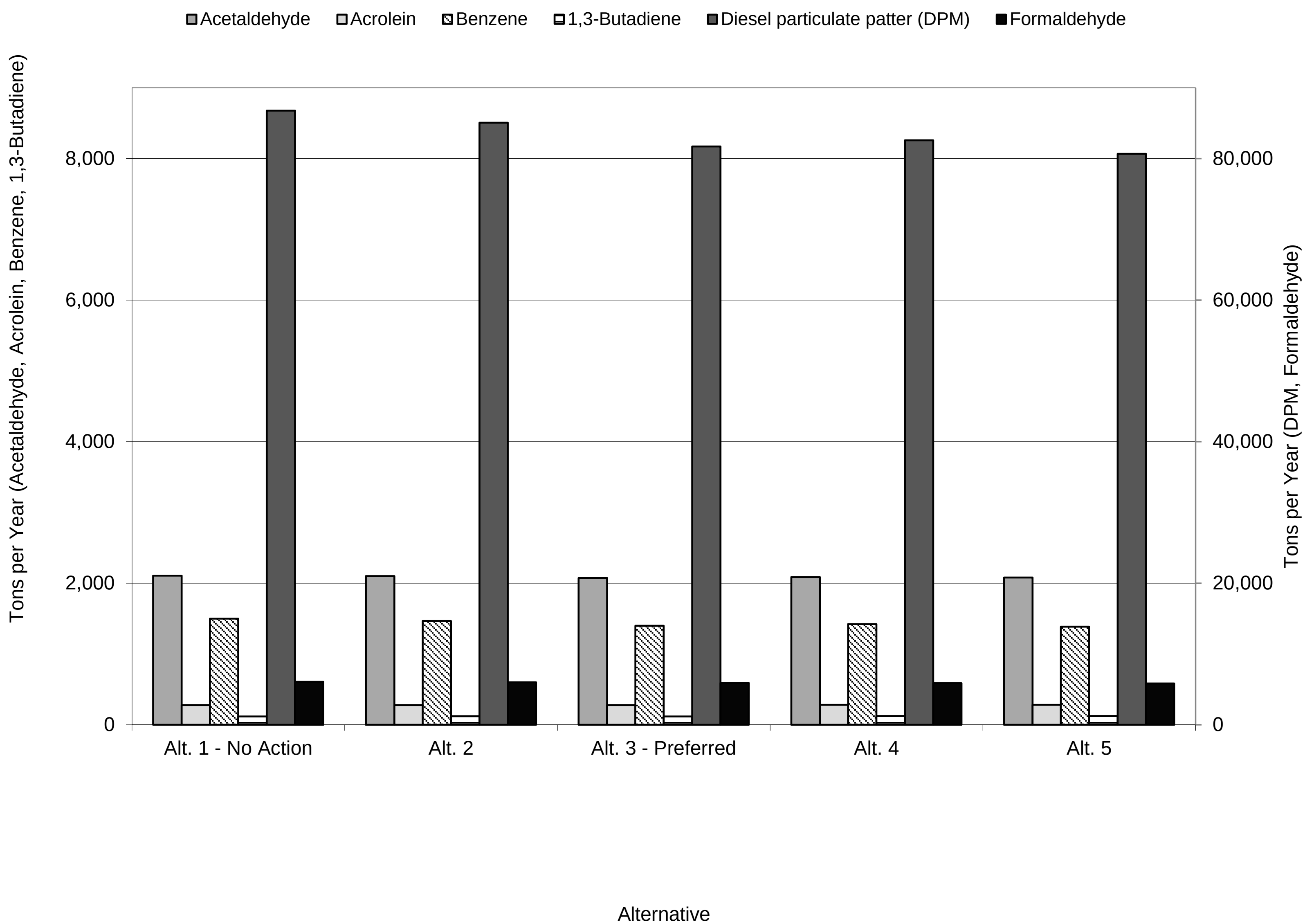


Figure 4.2.1-5 summarizes the changes over time in total national emissions of toxic air pollutants from HD vehicles under the Preferred Alternative. This figure indicates a consistent trend among the toxic air pollutants. Emissions decline from 2018 to 2040 due to increasingly stringent EPA regulation of emissions from vehicles and from reductions in upstream emissions from fuel production, but increase from 2040 to 2050 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 six components, consisting of two sources of emissions (downstream and upstream) for each of the three HD vehicle classes covered by the rule. (Emissions associated with the tractor-trailer classes include effects of the trailer standards.) To show the relationship among these six components for toxic air pollutants, Table 4.2.1-6 breaks down the total emissions of air toxic pollutants by component for calendar year 2040.

Table 4.2.1-7 lists the net change in nationwide emissions from HD vehicles for each of the toxic air pollutants and analysis years under the action alternatives compared to the No Action Alternative. The table shows that the magnitude of nationwide emissions changes tends to increase from 2018 to 2050. Figure 4.2.1-6 shows these changes in percentages for 2040. For each combination of pollutant and year, the emissions generally remain the same or decrease from Alternative 2 to Alternative 5, reflecting the generally increasing stringency of the alternatives. Alternative 4 is an exception, having emissions greater than under Alternative 3 for most pollutants and years for the reasons discussed in Sections 2.2and 4.2.1.1.1.

The differences in national emissions of toxic air pollutants among the action alternatives compared to the No Action Alternative range from less than 1 percent to 8 percent due to the similar interactions of the multiple factors described above for criteria pollutants in Section 4.2.1.1.1. The smaller differences are not expected to lead to measurable changes in concentrations of toxic air pollutants in the ambient air. For such small changes, the impacts of those action alternatives would be essentially equivalent. The larger differences in emissions could lead to changes in ambient pollutant concentrations.

Figure 4.2.1-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Direct and Indirect Impacts

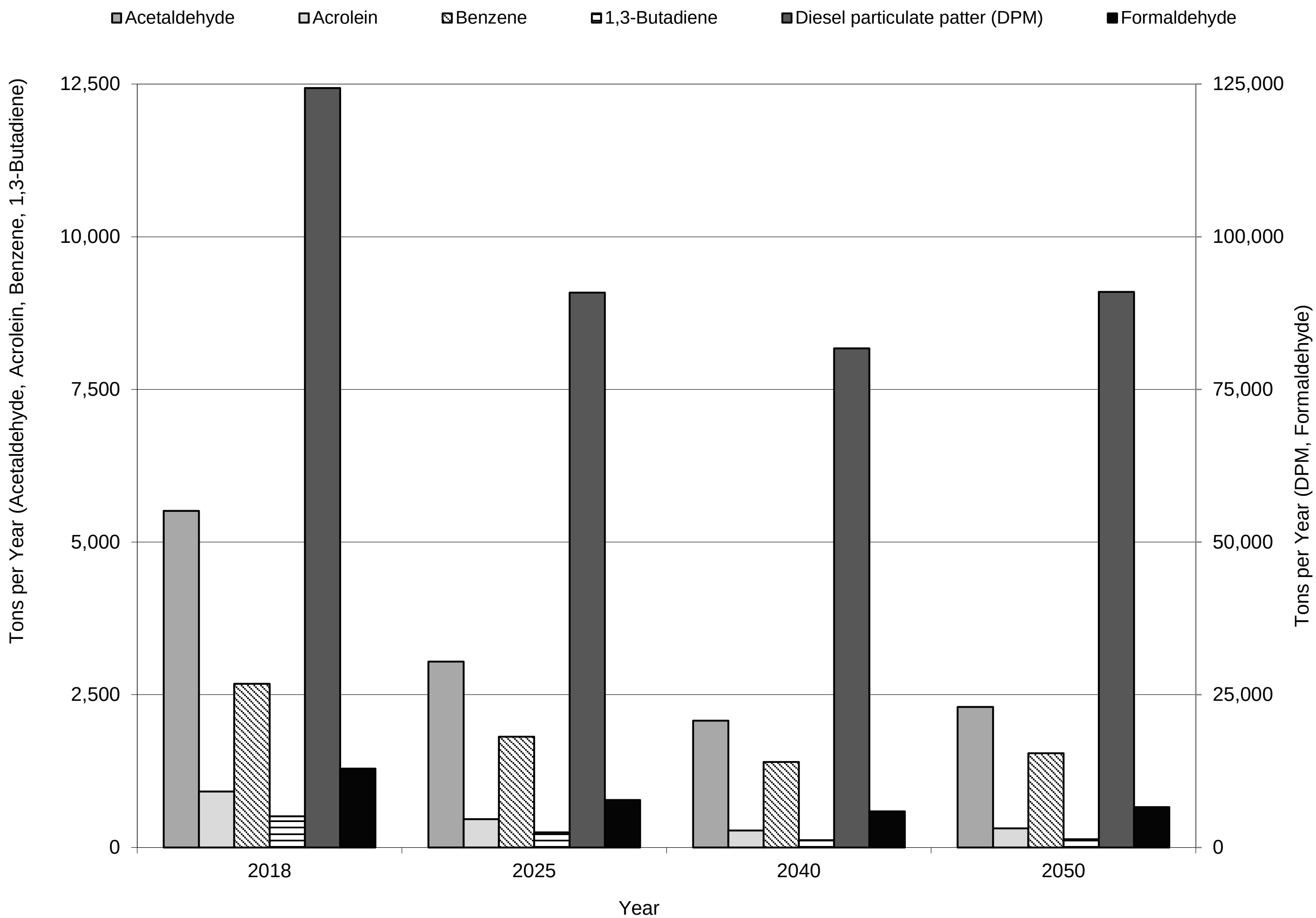


Table 4.2.1-6. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2040 from U.S. HD Vehicles, by Vehicle Type and Alternative, Direct and Indirect Impacts

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
Classes 2b–3 Work Trucks Tailpipe	464	467	469	469	470
Classes 2b–3 Work Trucks Upstream	5	5	5	5	4
Classes 3–8 Vocational Vehicles Tailpipe	564	564	565	565	565
Classes 3–8 Vocational Vehicles Upstream	52	49	45	47	44
Classes 7–8 Combination Unit Tailpipe	989	984	965	975	973
Classes 7–8 Combination Unit Upstream	33	31	26	28	25
Total	2,107	2,100	2,075	2,088	2,082
Acrolein					
Classes 2b–3 Work Trucks Tailpipe	51	52	52	52	52
Classes 2b–3 Work Trucks Upstream	1	1	1	1	1
Classes 3–8 Vocational Vehicles Tailpipe	75	75	75	75	75
Classes 3–8 Vocational Vehicles Upstream	5	4	4	4	4
Classes 7–8 Combination Unit Tailpipe	143	144	142	146	146
Classes 7–8 Combination Unit Upstream	5	4	4	4	4
Total	279	280	277	282	281
Benzene					
Classes 2b–3 Work Trucks Tailpipe	404	406	409	409	410
Classes 2b–3 Work Trucks Upstream	69	65	61	61	60
Classes 3–8 Vocational Vehicles Tailpipe	330	328	325	326	324
Classes 3–8 Vocational Vehicles Upstream	179	169	155	159	151
Classes 7–8 Combination Unit Tailpipe	239	236	225	232	228
Classes 7–8 Combination Unit Upstream	278	262	224	234	213
Total	1,499	1,466	1,399	1,422	1,385
1,3-Butadiene					
Classes 2b–3 Work Trucks Tailpipe	62	63	63	63	63
Classes 2b–3 Work Trucks Upstream	1	1	1	1	1
Classes 3–8 Vocational Vehicles Tailpipe	24	24	24	24	24
Classes 3–8 Vocational Vehicles Upstream	4	4	4	4	4
Classes 7–8 Combination Unit Tailpipe	12	15	15	20	21
Classes 7–8 Combination Unit Upstream	16	15	13	13	12
Total	119	122	119	125	125

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Diesel particulate matter (DPM)					
Classes 2b-3 Work Trucks Tailpipe	386	389	390	390	391
Classes 2b-3 Work Trucks Upstream	1,917	1,806	1,704	1,701	1,656
Classes 3-8 Vocational Vehicles Tailpipe	14,361	14,370	14,387	14,391	14,385
Classes 3-8 Vocational Vehicles Upstream	5,552	5,146	4,712	4,852	4,582
Classes 7-8 Combination Unit Tailpipe	44,978	44,925	44,747	44,750	44,672
Classes 7-8 Combination Unit Upstream	19,564	18,420	15,779	16,485	14,987
Total	86,758	85,055	81,719	82,569	80,672
Formaldehyde					
Classes 2b-3 Work Trucks Tailpipe	979	985	989	990	990
Classes 2b-3 Work Trucks Upstream	38	36	34	34	33
Classes 3-8 Vocational Vehicles Tailpipe	1,598	1,599	1,601	1,601	1,600
Classes 3-8 Vocational Vehicles Upstream	89	83	76	78	74
Classes 7-8 Combination Unit Tailpipe	3,091	3,035	2,976	2,943	2,924
Classes 7-8 Combination Unit Upstream	276	260	222	232	211
Total	6,071	5,998	5,899	5,878	5,833

Table 4.2.1-7. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b]

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
2018	0	0	0	0	0
2025	0	-1	-7	-6	-8
2040	0	-7	-31	-19	-25
2050	0	-8	-38	-22	-29
Acrolein					
2018	0	0	0	0	0
2025	0	0	0	1	1
2040	0	1	-2	2	2
2050	0	1	-3	2	2
Benzene					
2018	0	-1	-2	-2	-2
2025	0	-10	-25	-26	-40
2040	0	-33	-100	-78	-114
2050	0	-38	-118	-91	-132

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
1,3-Butadiene					
2018	0	0	0	0	0
2025	0	1	0	2	3
2040	0	2	0	6	5
2050	0	2	-1	6	6
Diesel particulate matter (DPM)					
2018	0	-33	-46	-49	-59
2025	0	-528	-1,177	-1,232	-1,902
2040	0	-1,702	-5,039	-4,189	-6,085
2050	0	-2,003	-6,087	-4,963	-7,198
Formaldehyde					
2018	0	0	0	0	0
2025	0	-21	-43	-63	-83
2040	0	-73	-172	-193	-238
2050	0	-87	-209	-229	-281

Notes:

[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.

Figure 4.2.1-6 (a)–(f). Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. HD Vehicles for 2040 by Action Alternative Compared to the No Action Alternative, Direct and Indirect Impacts

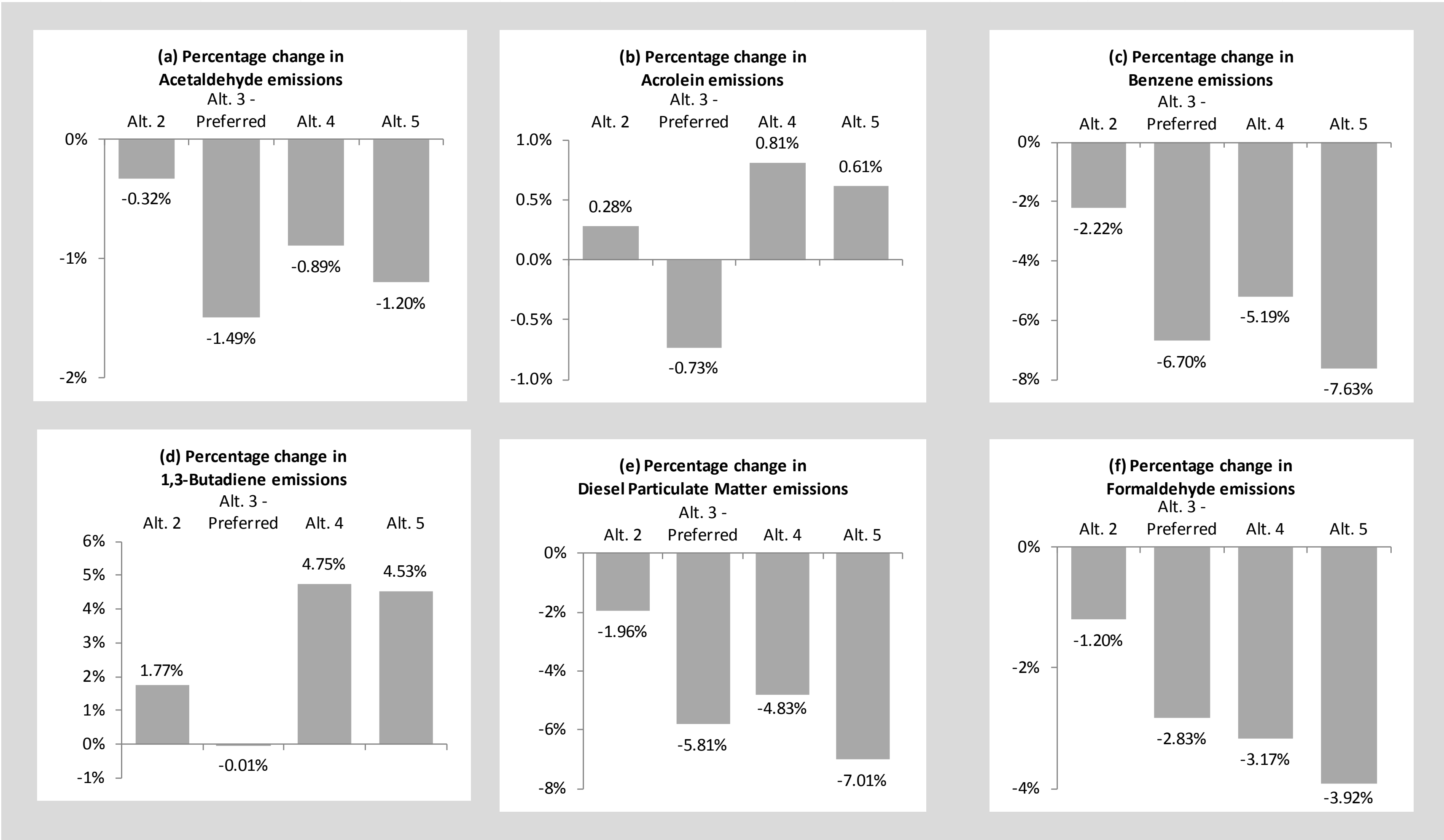


Table 4.2.1-8 summarizes the air toxics analysis results by nonattainment area.[29]

Table 4.2.1-8. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts

Criteria Pollutant	Maximum Increase/ Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Acetaldehyde	Maximum Increase	0.01	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (2008 8-hour)]
	Maximum Decrease	-6	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Acrolein	Maximum Increase	0.2	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (2008 8-hour)]
	Maximum Decrease	-2	2050	Alt. 5	AQCR 131: Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties (Minneapolis-St. Paul), MN [SO2 (1971 24-hour/Annual)]
Benzene	Maximum Increase	0	No increases are predicted for any alternatives		
	Maximum Decrease	-3	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
1,3-Butadiene	Maximum Increase	0.5	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (2008 8-hour)]
	Maximum Decrease	-1	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
Diesel particulate matter (DPM)	Maximum Increase	1	2025	Alt. 5	Atlanta, GA [Ozone (2008 8-hr)]
	Maximum Decrease	-373	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
Formaldehyde	Maximum Increase	0.03	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (2008 8-hour)]
	Maximum Decrease	-17	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]

Tables in Appendix A list the estimated emissions changes for each nonattainment area. For acetaldehyde and formaldehyde, Appendix A indicates that most nonattainment areas experience increases in emissions in 2018 under all the action alternatives, but decreases in 2025, 2040, and 2050

[29] EPA has not established NAAQS for airborne toxics. Therefore, none of these areas is classified as a nonattainment area as a result of airborne toxics emissions. Toxic air pollutant emissions data for nonattainment areas are provided for information only.

under all the action alternatives (except that for acetaldehyde most nonattainment areas experience increases in 2025 under Alternative 2). For acrolein and 1,3-butadiene, most nonattainment areas experience increases in emissions in all analysis years under all the action alternatives (except that for acrolein most nonattainment areas experience decreases in 2040 and 2050 under Alternative 3). For benzene, most nonattainment areas experience decreases in emissions in all analysis years under all the action alternatives. For DPM, most nonattainment areas experience decreases in emissions in all analysis years under all the action alternatives, but increases in 2025 under Alternatives 3, 4, and 5.

4.2.1.1.3 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 4.2.1-9). As described in Section 4.1.2.7.2, the changes in PM mortality shown in these tables are measured in several ways; benefits are measured under the Krewski methodology and the Lepeule methodology and at discount rates of 3 and 7 percent (*see* Section 4.1.2.7.2). While the number of PM mortalities varies between the two methods, the percent change in mortality across alternatives and years is equal. The health benefits across all outcomes generally remain the same or increase from Alternative 2 to Alternative 5 and from near-future (2018) to later years (2050). For each combination of pollutant and year, the health benefits generally increase from Alternative 2 to Alternative 5, reflecting the generally increasing stringency of the alternatives. Alternative 4 is an exception to this pattern, having fewer health benefits in 2040 and 2050 than Alternative 3 for the reasons discussed in Sections 2.2 and 4.2.1.1.1.

Table 4.2.1-9. Nationwide Changes in Health Outcomes (cases per year) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b]

Outcome and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Premature mortality - Krewski et al. (2009)					
2018	0	-2	-3	-4	-5
2025	0	-51	-110	-126	-183
2040	0	-172	-485	-437	-607
2050	0	-202	-585	-516	-715
Premature mortality – Lepeule et al. (2012)					
2018	0	-5	-8	-9	-10
2025	0	-117	-254	-289	-419
2040	0	-386	-1,086	-978	-1,358
2050	0	-452	-1,308	-1,155	-1,602
Acute bronchitis					
2018	0	-4	-6	-6	-7
2025	0	-82	-178	-203	-295
2040	0	-257	-723	-651	-904
2050	0	-301	-871	-768	-1,066
Work-loss days					
2018	0	-343	-483	-535	-643
2025	0	-6,890	-14,916	-16,981	-24,674
2040	0	-21,470	-60,492	-54,287	-75,494
2050	0	-25,194	-72,850	-64,091	-89,025

Outcome and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Emergency room visits – respiratory					
2018	0	-1	-2	-2	-2
2025	0	-26	-56	-64	-93
2040	0	-84	-235	-213	-295
2050	0	-98	-283	-251	-348

Notes:

[a] Incidence estimates are rounded to the nearest whole number.

[b] Negative changes indicate fewer health impacts; positive changes indicate additional health impacts.

[c] Changes for the No Action Alternative are shown as zero because it is the baseline to which the other alternatives are compared.

The monetized health benefits follow similar trends to the changes in health outcomes. Table 4.2.1-10 lists the corresponding monetized health benefits under the action alternatives compared to the No Action Alternative. Monetized health benefits are measured in several ways; benefits are measured under the Krewski methodology and the Lepeule methodology and at discount rates of 3 and 7 percent (*see* Section 4.1.2.7.2). Under each action alternative, the monetized health benefits increase from 2018 to 2050. In each analysis year, the monetized health benefits of each action alternative generally increase from Alternative 2 (least stringent) to Alternative 5 (most stringent). Alternative 4 is an exception, having lower monetized health benefits in 2040 and 2050 than Alternative 3 for the reasons discussed in Sections 2.2 and 4.2.1.1.1.

Table 4.2.1-10. Nationwide Monetized Health Benefits (U.S. million dollars per year, 2013$) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Direct and Indirect Impacts[a,b]

Rate and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
3-Percent Discount Rate					
Mortality (ages 30 and older) and Morbidity, Krewski et al. (2009)					
2018	$0	$26	$36	$40	$49
2025	$0	$548	$1,186	$1,353	$1,964
2040	$0	$1,978	$5,572	$5,010	$6,962
2050	$0	$2,321	$6,711	$5,914	$8,210
Mortality (ages 30 and older) and Morbidity, Lepeule et al. (2012)					
2018	$0	$59	$83	$92	$110
2025	$0	$1,238	$2,679	$3,056	$4,437
2040	$0	$4,411	$12,424	$11,186	$15,536
2050	$0	$5,176	$14,963	$13,207	$18,320
7-Percent Discount Rate					
Mortality (ages 30 and older) and Morbidity, Krewski et al. (2009)					
2018	$0	$23	$33	$37	$44
2025	$0	$492	$1,064	$1,214	$1,762
2040	$0	$1,769	$4,984	$4,483	$6,229
2050	$0	$2,077	$6,003	$5,293	$7,345
Mortality (ages 30 and older) and Morbidity, Lepeule et al. (2012)					

Rate and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
2018	$0	$52	$73	$81	$98
2025	$0	$1,112	$2,408	$2,745	$3,986
2040	$0	$3,994	$11,247	$10,130	$14,066
2050	$0	$4,687	$13,546	$11,961	$16,588

Notes:

[a] Monetized health benefit estimates are rounded to the nearest whole number

[b] Positive changes indicate greater benefits and fewer health impacts; negative changes indicate fewer benefits and additional health impacts.

[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.

Sections 4.2.1.2 through 4.2.1.5 describe the results of the analysis of emissions for Alternatives 1 through 5 in more detail. The magnitude of emissions change from one alternative to the next generally increases, with a few exceptions that are discussed in these sections, between Alternative 2 and Alternative 5 consistent with increases in overall fuel efficiency.

4.2.1.2 Alternative 1 - No Action

4.2.1.2.1 Criteria Pollutants

The No Action Alternative assumes market-based gains in new HD vehicle fuel efficiency after 2018. Current trends in the levels of criteria pollutant emissions from vehicles would continue under the No Action Alternative, with emissions of CO, NO_X, PM2.5, and VOCs continuing to decline due to the EPA emissions standards (*see* Section 4.1), despite a growth in total VMT from 2018 to 2040, but increasing from 2040 to 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.1-1). Total emissions of SO_2 under the No Action Alternative are predicted to increase from 2018 to 2050 because declines due to market-based gains in new vehicle HD vehicle fuel efficiency are more than offset by growth in VMT beginning before 2018. 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 shown for the No Action Alternative in Table 4.2.1-1.

Figure 4.2.1-1 shows that emissions of NO_X, PM2.5, SO_2, and VOCs under the No Action Alternative in 2040 would be greater than emissions under all of the action alternatives. Changes in emissions of all criteria pollutants would generally be greatest in 2050 under Alternative 5, in which emissions would range up to 22 percent less than under the No Action Alternative (*see* Table 4.2.1-1).

4.2.1.2.2 Toxic Air Pollutants

EPA regulates toxic air pollutants from motor vehicles through vehicle emissions 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. Emissions would continue to decline in early years due to the EPA emissions standards (*see* Section 4.1.1) despite a growth in total VMT, reaching a minimum in 2040, but increasing in 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.1-5). The No Action Alternative would not change the current fuel efficiency standards for HD vehicles and, therefore, would not result in any change in toxic air pollutant emissions nationally or in nonattainment areas beyond projected trends shown for the No Action Alternative in Table 4.2.1-5.

Table 4.2.1-5 shows that emissions of acetaldehyde and formaldehyde under the No Action Alternative are the same as emissions under all of the action alternatives in 2018, and are greater than emissions under all of the action alternatives in 2025, 2040, and 2050. Emissions of acrolein and 1,3-butadiene under the No Action Alternative are the same as or less than emissions under all of the action alternatives, except for the Preferred Alternative in 2040 and 2050. Emissions of benzene and DPM under the No Action Alternative are greater than emissions under all of the action alternatives.

Changes in emissions of all toxic air pollutants are greatest in 2050 (see Table 4.2.1-7). The largest changes in emissions of acetaldehyde and acrolein occur under Alternative 3, and the largest changes in emissions of benzene, 1,3-butadiene, DPM, and formaldehyde occur under Alternative 5. The changes in emissions range from 5 percent greater to 8 percent less 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 2050 due to growth in total VMT, which more than offsets reductions due to the EPA vehicle emissions standards (*see* Section 4.1.1). The human health-related trends would continue (*see* Section 4.1.1 and Tables 4.2.1-9 and 4.2.1-10). The No Action Alternative would not result in any additional increase or decrease in human health effects throughout the United States.

4.2.1.3 Alternative 2

4.2.1.3.1 Criteria Pollutants

Table 4.2.1-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 2 (and other action alternatives) compared to the No Action Alternative. Figure 4.2.1-3 shows these changes in percentages for 2040. Under Alternative 2, nationwide emissions of all criteria pollutants would decrease compared to the No Action Alternative (except for CO in 2018). Alternative 2 is the least stringent of all the action alternatives, and the emissions reductions under Alternative 2 would be less than those under the Preferred Alternative, Alternative 4, and Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 2 compared to the No Action Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 2, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in emissions in 2025, 2040, and 2050. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.1.3.2 Toxic Air Pollutants

Table 4.2.1-7 shows the changes in nationwide emissions of toxic air pollutants under Alternative 2 (and other action alternatives) compared to the No Action Alternative. Figure 4.2.1-6 shows these changes in percentages for 2040. Compared to the No Action Alternative, Alternative 2 would result in the same emissions of acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde in 2018, but decreased emissions of benzene and DPM in 2018. Alternative 2 would result in the same or increased emissions of acrolein and 1,3-butadiene in 2025, 2040, and 2050, but decreased emissions of acetaldehyde, benzene, DPM and formaldehyde in 2025, 2040, and 2050. Alternative 2 would result in the same or higher emissions than would the Preferred Alternative, Alternative 4, or Alternative 5 for most pollutants and years; Alternative 2 would result in lower emissions than would Alternative 4 and Alternative 5 for acrolein and 1,3-butadiene in 2025, 2040, and 2050 (see Table 4.2.1-5).

At the national level, emissions of all toxic air pollutants could decrease under Alternative 2 compared to the No Action Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, most nonattainment areas would experience increases in emissions in 2018 and 2025 under Alternative 2, but decreases in 2040 and 2050. For acrolein and 1,3-butadiene, most nonattainment areas would experience increases in emissions in all analysis years under Alternative 2. For benzene and DPM, most nonattainment areas would experience decreases in emissions in all analysis years under Alternative 2. For formaldehyde, most nonattainment areas would experience increases in emissions in 2018 under Alternative 2, but decreases in 2025, 2040 and 2050 (*see* Appendix A).

4.2.1.3.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 2 compared to the No Action Alternative (*see* Table 4.2.1-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.1-10, the monetized health impacts under Alternative 2 would range from a minimum benefit of $23 million per year to a maximum benefit of approximately $5.2 billion per year, depending on methodology, discount rate, and year. The monetized health benefits under Alternative 2 are less than those under the other action alternatives.

4.2.1.4 Alternative 3 - Preferred Alternative

4.2.1.4.1 Criteria Pollutants

Table 4.2.1-3 shows the changes in nationwide emissions of criteria pollutants under the Preferred Alternative (and other action alternatives) compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-3 shows these changes in percentages for 2040. Figure 4.2.1-2 shows criteria pollutant emissions under the Preferred Alternative by year. Under this alternative, emissions of all criteria pollutants would decrease compared to the No Action Alternative (except for CO in 2018). This alternative would reduce emissions more than Alternative 2. Emissions under the Preferred Alternative would be less than under Alternative 2, but greater than under Alternative 4 (except for CO in 2018, and PM2.5, SO_2, and VOCs in 2040 and 2050) and Alternative 5 (except for CO in 2018).

At the national level, emissions of all criteria air pollutants could decrease under the Preferred Alternative because the increases in vehicle emissions due to the rebound effect would be more than offset by reductions in upstream emissions of criteria air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under the Preferred Alternative, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2040, and 2050. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.1.4.2 Toxic Air Pollutants

Table 4.2.1-7 shows the changes in nationwide emissions of toxic air pollutants under the Preferred Alternative (and other action alternatives) compared to the No Action Alternative. Figure 4.2.1-5 shows toxic pollutant emissions under the Preferred Alternative by year. Figure 4.2.1-6 shows these changes in percentage terms for 2040. Compared to the No Action Alternative, the Preferred Alternative would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. The Preferred Alternative would result in the same or lower emissions than would Alternative 2. The Preferred Alternative would result in the same or lower emissions than would Alternative 4 for acetaldehyde, acrolein, benzene (in 2018, 2040, and 2050), 1,3-butadiene, DPM (in 2040 and 2050), and formaldehyde (in 2018), but higher emissions than would Alternative 4 for benzene (in 2025), DPM (in 2018 and 2025), and formaldehyde (in 2025, 2040 and 2050). The Preferred Alternative would result in the same or lower emissions than would Alternative 5 for acetaldehyde (in 2018, 2040, and 2050), acrolein, benzene (in 2018), 1,3-butadiene, and formaldehyde (in 2018), but higher emissions than would Alternative 5 for acetaldehyde (in 2025), benzene (in 2025, 2040, and 2050), DPM, and formaldehyde (in 2025, 2040 and 2050).

At the national level, emissions of all toxic air pollutants could decrease under the Preferred Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under the Preferred Alternative, but decreases in 2025, 2040, and 2050. For acrolein, most nonattainment areas experience increases in emissions in 2018 and 2025 under the Preferred Alternative, but decreases in 2040 and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under the Preferred Alternative. For 1,3-butadiene, most nonattainment areas experience increases in emissions in all analysis years under the Preferred Alternative. For DPM, most nonattainment areas experience decreases in emissions in 2018, 2040, and 2050 under the Preferred Alternative, but increases in 2025 (*see* Appendix A).

4.2.1.4.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under the Preferred Alternative compared to the No Action Alternative (*see* Table 4.2.1-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.1-10, the monetized health impacts under the Preferred Alternative would range from a minimum benefit of $33 million per year to a maximum benefit of approximately $15.0 billion per year, depending on methodology, discount rate, and year. The monetized health benefits under the Preferred Alternative are greater than those under Alternative 2 but less than those under Alternative 4 (except in 2040 and 2050). In 2040 and 2050, the monetized health benefits under the Preferred Alternative are greater than those under Alternative 4. The monetized health benefits under the Preferred Alternative are less than those under Alternative 5 in all analysis years.

4.2.1.5 Alternative 4

4.2.1.5.1 Criteria Pollutants

Table 4.2.1-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 4 compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-3 shows these changes in percentages for 2040. Under this alternative, emissions of all criteria pollutants would decrease compared to the No Action Alternative (except for CO in 2018). This alternative would reduce emissions more than Alternative 2 and the Preferred Alternative (except that CO emissions under Alternative 4 would be slightly higher than under the Preferred Alternative in 2018, and emissions of PM2.5, SO_2, and VOC under Alternative 4 would be higher than under the Preferred Alternative in 2040 and 2050). Emissions under Alternative 4 would be greater than under Alternative 5 (except for CO in 2018).

At the national level, emissions of all criteria air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect would be more than offset by reductions in upstream emissions of criteria air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 4, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2040, and 2050. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.1.5.2 Toxic Air Pollutants

Table 4.2.1-7 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 4.2.1-6 shows these changes in percentage terms for 2040. Compared to the No Action Alternative, Alternative 4 would result in the same or reduced emissions of acetaldehyde, acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions of acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Alternative 4 would result in the same or lower emissions than would Alternative 2 for acetaldehyde, acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions than would Alternative 2 for acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Alternative 4 would result in the same or lower emissions than would the Preferred Alternative for acetaldehyde (in 2018), acrolein (in 2018), benzene (in 2018 and 2025), 1,3-butadiene (in 2018), DPM (in 2018 and 2025), and formaldehyde, but higher emissions than would the Preferred Alternative for acetaldehyde (in 2025, 2040, and 2050), acrolein (in 2025, 2040, and 2050), benzene (in 2040 and 2050), 1,3-butadiene (in 2025, 2040, and 2050), and DPM (in 2040 and 2050). Alternative 4 would result in the same or lower emissions than would Alternative 5 for acetaldehyde (in 2018), acrolein (in 2018 and 2025), benzene (in 2018), 1,3-butadiene(in 2018, 2025, and 2040), and formaldehyde (in 2018), but higher emissions than would Alternative 5 for acetaldehyde (in 2025, 2040, and 2050), acrolein (in 2040 and 2050), benzene (in 2025, 2040, and 2050), 1,3-butadiene (in 2050), DPM, and formaldehyde (in 2025, 2040, and 2050).

At the national level, as with the less-stringent alternatives, emissions of all toxic air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas.

For acetaldehyde and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 4, but decreases in 2025, 2040, and 2050. For acrolein and 1,3-butadiene, most nonattainment areas experience increases in emissions in all analysis years under Alternative 4. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 4. For DPM, most nonattainment areas experience increases in emissions in 2025 under Alternative 4, but decreases in 2018, 2040, and 2050 (*see* Appendix A).

4.2.1.5.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 4 compared to the No Action Alternative (*see* Table 4.2.1-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.1-10, the monetized health impacts under Alternative 4 would range from a minimum benefit of $37 million per year to a maximum benefit of approximately $13.2 billion per year, depending on methodology, discount rate, and year. The monetized benefits under Alternative 4 are greater than those under Alternative 2 in all analysis years, and greater than those under the Preferred Alternative in 2018 and 2025, but less than those under the Preferred Alternative in 2040 and 2050, and less than those under Alternative 5 in all analysis years.

4.2.1.6 Alternative 5

4.2.1.6.1 Criteria Pollutants

Table 4.2.1-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 5 compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-3 shows these changes in percentages for 2040. Under this alternative, emissions of all criteria pollutants would decrease compared to the No Action Alternative (except for CO in 2018). This alternative would reduce emissions (except for CO in 2018) more than Alternative 2, the Preferred Alternative, and Alternative 4. Emissions under Alternative 5 (except for CO in 2018) would be less than under Alternative 2, the Preferred Alternative, and Alternative 4. For CO in 2018, emissions under Alternative 5 would be greater than under Alternative 2, the Preferred Alternative, and Alternative 4.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 5 because the increases in vehicle emissions due to the rebound effect would be more than offset by reductions in upstream emissions of criteria air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 5, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2040, and 2050. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.1.6.2 Toxic Air Pollutants

Table 4.2.1-7 shows the changes in nationwide emissions of toxic air pollutants under Alternative 5 compared to the No Action Alternative and the other action alternatives. Figure 4.2.1-4 shows toxic pollutant emissions under Alternative 5 for 2040. Figure 4.2.1-6 shows these changes in percentage terms for 2040. Compared to the No Action Alternative, Alternative 5 would result in the same or reduced emissions of acetaldehyde, acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions of acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Compared to Alternative 2, Alternative 5 would result in the same or lower emissions for acetaldehyde, acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions of acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Compared to the Preferred Alternative, Alternative 5 would result in the same or lower emissions of acetaldehyde (in 2018 and 2025), acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions of acetaldehyde (in 2040 and 2050), acrolein (in 2025, 2040 and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Compared to Alternative 4, Alternative 5 would result in the same or lower emissions of all toxic air pollutants.

At the national level, as with the less-stringent alternatives, emissions of all toxic air pollutants could decrease under Alternative 5 because the increases in vehicle emissions due to the rebound effect would be more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 5, but decreases in 2025, 2040, and 2050. For acrolein and 1,3-butadiene, most nonattainment areas experience increases in emissions in all analysis years under Alternative 5. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 5. For DPM, most nonattainment areas experience increases in emissions in 2025 under Alternative 5, but decreases in 2018, 2040, and 2050 (*see* Appendix A).

4.2.1.6.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 5 compared to the No Action Alternative (*see* Table 4.2.1-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.1-10, the monetized health impacts under Alternative 5 would range from a minimum benefit of $44 million per year to a maximum benefit of approximately $18.3 billion per year, depending on methodology, discount rate, and year. The monetized benefits under Alternative 5 are greater than those under Alternative 2, the Preferred Alternative, and Alternative 4.

4.2.2 Cumulative Impacts

4.2.2.1 Results of the Analysis

This section examines cumulative air quality impacts of the action alternatives, using the assumptions discussed in Section 2.3.[30] The tables and figures in Section 4.2.2 and its subsections present the projected cumulative impacts of the action alternatives on air quality. Following the comparative overview in this section, Sections 4.2.2.2 through 4.2.2.5 describe the results of the analysis of cumulative impacts under Alternatives 1 through 5 in more detail.

4.2.2.1.1 Criteria Pollutants Overview

Table 4.2.2-1 summarizes the total upstream and downstream[31] national emissions from HD vehicles by alternative for each of the criteria pollutants and analysis years. Figure 4.2.2-1 illustrates this information for 2040, the forecast year by which a large proportion of HD vehicle VMT would be accounted for by vehicles that meet standards as set forth under the rulemaking. Figure 4.2.2-2 summarizes the changes over time in total national emissions of criteria pollutants from HD vehicles under the Preferred Alternative. Figures 4.2.2-1 and 4.2.2-2 show a consistent trend among the criteria pollutants. Emissions of CO, NO_X, PM2.5, and VOCs would decrease due to the EPA emissions standards (*see* Section 4.1), despite a growth in total VMT from 2018 to 2040, but increase from 2040 to 2050 because continued growth in total VMT during that period would overwhelm the initial decreases (*see* Table 4.2.2-1 and Figure 4.2.2-2). (Note that continued growth in VMT is projected to occur under all alternatives.)

Emissions of SO_2 under all alternatives are predicted to increase from 2018 to 2050 because declines due to gains in new HD vehicle fuel efficiency are more than offset by continuing growth in VMT. The Preferred Alternative, Alternative 4, and Alternative 5 are sufficiently stringent that fuel savings would offset VMT growth even in the early years of Phase 2 implementation, and SO_2 emissions would decrease continuously from 2018 to 2025 or 2040 (depending on the alternative) before increasing by 2050 due to continued VMT growth.

[30] As explained in Chapter 2, the cumulative impacts analysis compares the same action alternatives with a No Action Alternative that generally assumes no increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond (i.e., no increase beyond the 2014-2018 Phase 1 standards). In other words, this baseline generally does not take into account market-based incentives for improving fuel efficiency. By comparing the action alternatives to this baseline, the cumulative impacts analysis reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 and the direct and indirect impacts of Phase 2 HD standards associated with each action alternative.

[31] Downstream emissions do not include evaporative emissions from vehicle fuel systems due to modeling limitations.

Table 4.2.2-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
2018	1,755,600	1,755,683	1,755,669	1,755,689	1,755,706
2025	1,382,011	1,374,076	1,368,799	1,358,075	1,351,712
2040	1,259,285	1,231,146	1,207,915	1,185,953	1,172,921
2050	1,435,036	1,401,314	1,372,897	1,347,873	1,332,893
Nitrogen oxides (NO_X)					
2018	1,839,027	1,838,795	1,838,657	1,838,649	1,838,480
2025	1,066,761	1,054,972	1,043,547	1,032,988	1,022,201
2040	792,227	748,440	692,418	677,516	651,318
2050	883,745	831,293	762,411	746,849	716,200
Particulate matter (PM2.5)					
2018	86,451	86,422	86,411	86,407	86,399
2025	51,612	51,048	50,494	50,458	49,929
2040	40,043	38,072	35,366	36,016	34,519
2050	44,649	42,308	39,001	39,863	38,096
Sulfur dioxide (SO_2)					
2018	113,763	113,629	113,559	113,528	113,481
2025	119,481	116,312	113,109	112,544	109,422
2040	134,684	124,168	109,222	113,065	104,600
2050	149,790	137,365	119,180	124,303	114,367
Volatile organic compounds (VOC)					
2018	253,163	252,969	252,901	252,851	252,795
2025	179,798	177,101	174,513	174,502	172,298
2040	156,913	149,139	137,745	141,503	135,479
2050	172,682	163,686	150,041	154,845	147,844

Figure 4.2.2-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2040 by Alternative, Cumulative Impacts

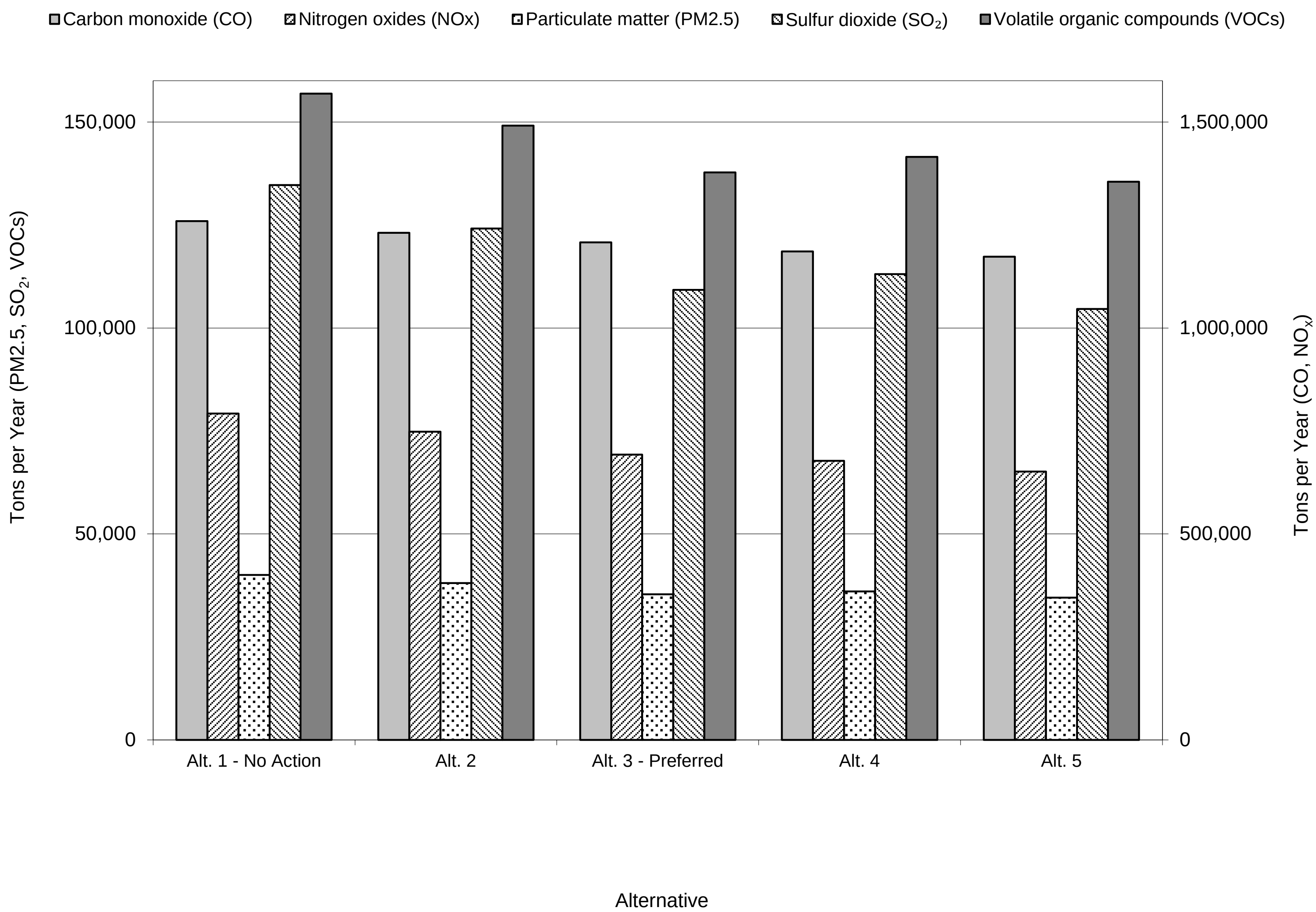
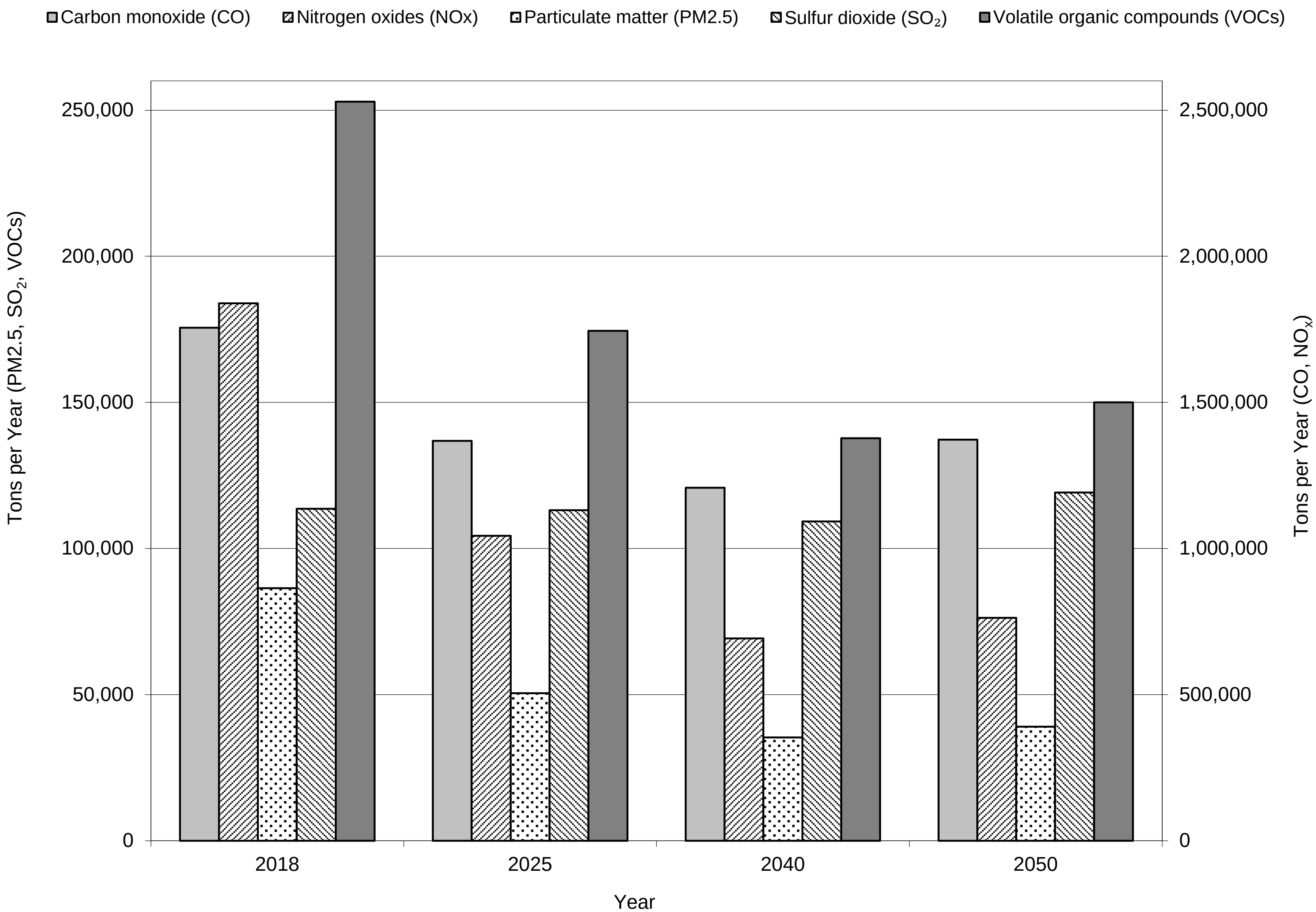


Figure 4.2.2-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Cumulative Impacts



The timing of the increases between 2018 and 2050 varies by alternative. EPA regulates vehicle SO_2 emissions by limiting the concentration of sulfur in fuel and has not established tailpipe emissions standards for SO_2. As a result, SO_2 emissions vary only with total fuel consumption. Under the No Action Alternative, which assumes neither NHTSA nor EPA promulgate Phase 2 standards (i.e., the No Action Alternative), total fuel consumption would rise as VMT grows, and SO_2 emissions would increase continuously from 2018 to 2050. Alternative 2 is not sufficiently stringent for fuel savings to offset VMT growth, so SO_2 emissions would increase continuously from 2018 to 2050 under Alternative 2 as well. Under the Preferred Alternative and Alternative 5, SO_2 emissions decrease from 2018 to 2040 as the proportion of all vehicles that meets the Phase 2 standards increases, before emissions increase again by 2050 due to continued VMT growth. Under Alternative 4, SO_2 emissions decrease from 2018 to 2025 but then increase from 2025 to 2050, because some provisions of Alternative 4 are less stringent than those of Alternative 3, as discussed in Section 2.2.

Total emissions are made up of six components, consisting of two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the three vehicle classes covered by the rule: Classes 2b–3 HD pickups and vans, Classes 3–8 vocational vehicles, and Classes 7–8 tractor-trailers. (Emissions associated with the tractor-trailer classes include effects of the trailer standards.) To show the relationship among these six components for criteria pollutants, Table 4.2.2-2 breaks down the total emissions of criteria pollutants by component for calendar year 2040.

Table 4.2.2-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2040 from U.S. HD Vehicles, by Vehicle Type and Alternative, Cumulative Impacts

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
Classes 2b–3 Work Trucks Tailpipe	282,282	284,549	286,274	286,344	287,084
Classes 2b–3 Work Trucks Upstream	11,196	10,432	9,852	9,832	9,587
Classes 3–8 Vocational Vehicles Tailpipe	676,690	676,483	676,365	676,415	676,331
Classes 3–8 Vocational Vehicles Upstream	15,610	14,459	13,241	13,633	12,875
Classes 7–8 Combination Unit Tailpipe	215,884	192,309	176,856	152,372	143,991
Classes 7–8 Combination Unit Upstream	57,622	52,914	45,328	47,357	43,053
Total	1,259,285	1,231,146	1,207,915	1,185,953	1,172,921
Nitrogen oxides (NO_X)					
Classes 2b–3 Work Trucks Tailpipe	41,171	41,478	41,663	41,675	41,727
Classes 2b–3 Work Trucks Upstream	27,369	25,509	24,094	24,046	23,447
Classes 3–8 Vocational Vehicles Tailpipe	106,893	106,323	106,046	106,323	106,006
Classes 3–8 Vocational Vehicles Upstream	38,190	35,376	32,395	33,355	31,500
Classes 7–8 Combination Unit Tailpipe	437,825	410,479	377,479	356,418	343,453
Classes 7–8 Combination Unit Upstream	140,779	129,275	110,741	115,700	105,184
Total	792,227	748,440	692,418	677,516	651,318
Particulate matter (PM2.5)					
Classes 2b–3 Work Trucks Tailpipe	1,932	1,948	1,959	1,959	1,963
Classes 2b–3 Work Trucks Upstream	2,300	2,144	2,024	2,020	1,969
Classes 3–8 Vocational Vehicles Tailpipe	4,089	4,084	4,084	4,087	4,083

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Classes 3–8 Vocational Vehicles Upstream	4,379	4,062	3,720	3,830	3,618
Classes 7–8 Combination Unit Tailpipe	12,051	11,792	11,551	11,553	11,461
Classes 7–8 Combination Unit Upstream	15,292	14,042	12,029	12,568	11,425
Total	40,043	38,072	35,366	36,016	34,519
Sulfur dioxide (SO_2)					
Classes 2b–3 Work Trucks Tailpipe	575	580	583	583	584
Classes 2b–3 Work Trucks Upstream	17,180	16,014	15,123	15,094	14,711
Classes 3–8 Vocational Vehicles Tailpipe	1,081	1,003	918	946	893
Classes 3–8 Vocational Vehicles Upstream	23,811	22,052	20,194	20,792	19,636
Classes 7–8 Combination Unit Tailpipe	3,712	3,411	2,924	3,059	2,783
Classes 7–8 Combination Unit Upstream	88,325	81,108	69,479	72,590	65,993
Total	134,684	124,168	109,222	113,065	104,600
Volatile organic compounds (VOC)					
Classes 2b–3 Work Trucks Tailpipe	12,561	12,661	12,729	12,733	12,758
Classes 2b–3 Work Trucks Upstream	31,712	29,552	27,890	27,838	27,150
Classes 3–8 Vocational Vehicles Tailpipe	21,345	20,800	20,050	20,303	19,838
Classes 3–8 Vocational Vehicles Upstream	25,466	23,971	21,956	22,615	21,390
Classes 7–8 Combination Unit Tailpipe	28,032	27,447	25,387	26,952	26,103
Classes 7–8 Combination Unit Upstream	37,797	34,708	29,732	31,063	28,240
Total	156,913	149,139	137,745	141,503	135,479

Table 4.2.2-3 lists the net changes in nationwide criteria pollutant emissions from HD vehicles for each action alternative for each criteria pollutant and analysis year compared to the No Action Alternative in the same year. Figure 4.2.2-3 shows these changes in percentages for 2040. As a general trend, total emissions of each pollutant in a given year decrease from Alternative 2 through Alternative 5, as each successive alternative generally becomes more stringent. In Table 4.2.2-3, this trend shows as a growing difference between the No Action Alternative and each action alternative from Alternative 2 through Alternative 5. However, the magnitudes of the declines in total emissions are not consistent across all pollutants, and there are some emissions increases for CO, which reflects the complex interactions between tailpipe emissions rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the standards, upstream emissions rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and increases in VMT. Instances where downstream (tailpipe) emissions are predicted to increase[32] (on a per-VMT basis) in the action alternatives would be attributable to shifts in modeled technology adoption from the baseline.

Tables 4.2.2-1 and 4.2.2-3 show that total emissions of all criteria pollutants in a given year would decrease from Alternative 1 through Alternative 5 (except that CO emissions would increase slightly

[32] Criteria pollutant emissions do not increase above the vehicle emissions standards but rather increase within the allowable "headroom" of the standard.

from Alternative 1 to Alternative 5 in 2018, and emissions of PM2.5, SO_2, and VOCs increase slightly from the Preferred Alternative to Alternative 4 in 2040 and 2050).

Under each action alternative compared to the No Action Alternative, the greatest relative reductions in emissions among the criteria pollutants would occur for NO_X and SO_2, for which emissions would decrease by as much as 24 percent by 2050 compared to the No Action Alternative (*see* Tables 4.2.2-1 and 4.2.2-3). Percentage reductions in emissions of CO, PM2.5, and VOCs compared to the No Action Alternative would be less.

Table 4.2.2-3. Nationwide Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b]

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon monoxide (CO)					
2018	0	84	69	89	106
2025	0	-7,936	-13,212	-23,936	-30,299
2040	0	-28,139	-51,369	-73,331	-86,363
2050	0	-33,723	-62,139	-87,164	-102,143
Nitrogen oxides (NO_X)					
2018	0	-232	-370	-377	-546
2025	0	-11,788	-23,214	-33,773	-44,559
2040	0	-43,787	-99,809	-114,710	-140,909
2050	0	-52,452	-121,334	-136,896	-167,545
Particulate matter (PM2.5)					
2018	0	-30	-40	-44	-52
2025	0	-564	-1,118	-1,154	-1,682
2040	0	-1,971	-4,677	-4,026	-5,524
2050	0	-2,341	-5,648	-4,786	-6,553
Sulfur dioxide (SO_2)					
2018	0	-134	-204	-235	-282
2025	0	-3,169	-6,373	-6,937	-10,059
2040	0	-10,516	-25,462	-21,619	-30,085
2050	0	-12,425	-30,610	-25,487	-35,423
Volatile organic compounds (VOC)					
2018	0	-195	-262	-312	-368
2025	0	-2,697	-5,284	-5,296	-7,500
2040	0	-7,774	-19,168	-15,410	-21,434
2050	0	-8,996	-22,641	-17,837	-24,838

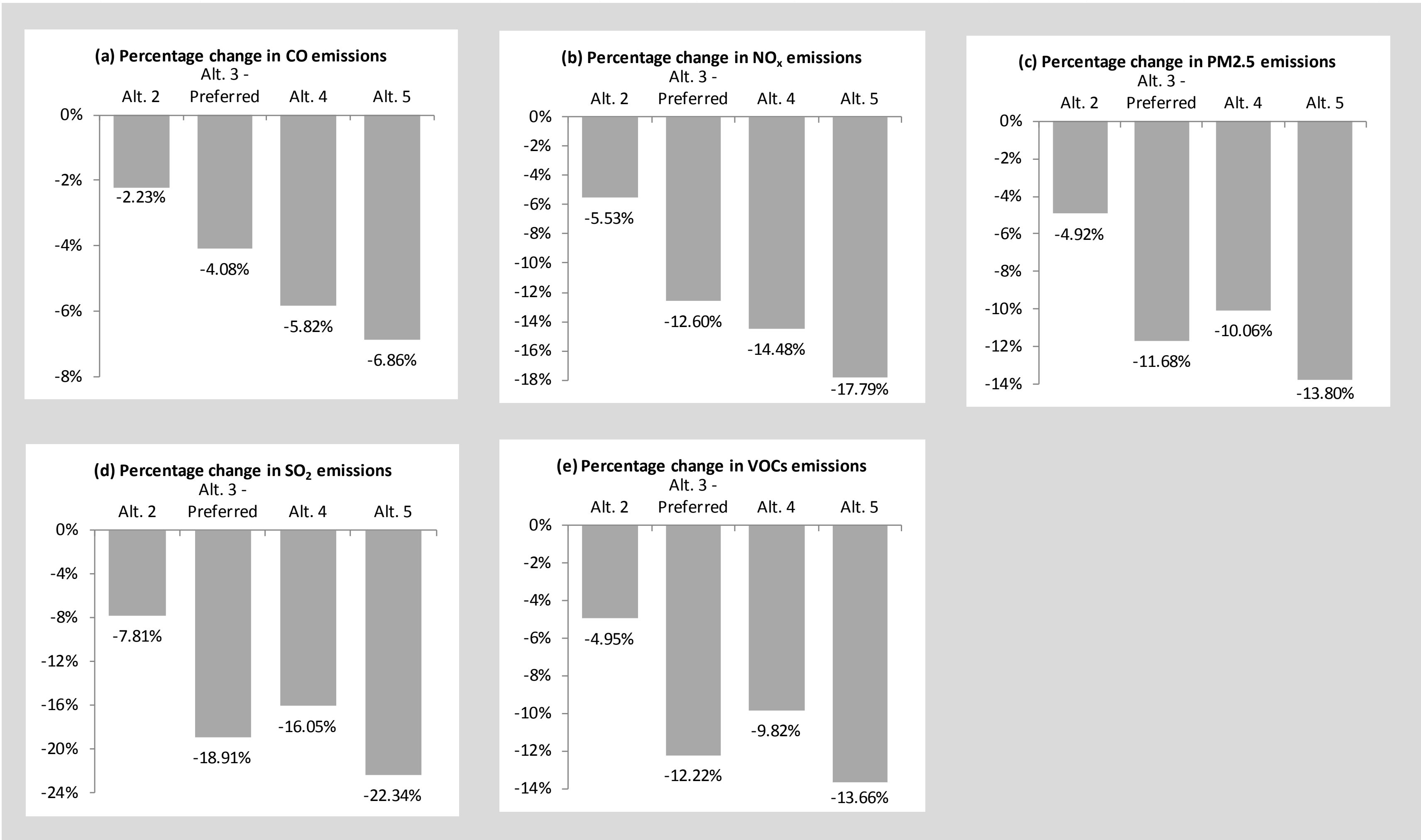
Notes:

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

[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.

Figure 4.2.2-3 (a)–(e). Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. HD Vehicles for 2040 by Action Alternative Compared to the No Action Alternative, Cumulative Impacts



The differences in national emissions of criteria air pollutants among the action alternatives compared to the No Action Alternative would range from less than 1 percent to 24 percent due to the interactions of the multiple factors described above. The smaller differences are not expected to lead to measurable changes in concentrations of criteria pollutants in the ambient air. The larger differences in emissions could lead to changes in ambient pollutant concentrations.

Table 4.2.2-4 summarizes the criteria air pollutant analysis results by nonattainment area. Tables in Appendix A list the emissions changes for each nonattainment area. For CO, Appendix A indicates that most nonattainment areas would experience increases in emissions in 2018 under all the action alternatives, but most would experience decreases in emissions in 2025, 2040, and 2050 under all the action alternatives. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions across all alternatives and years.

Table 4.2.2-4. Maximum Changes in Criteria Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Cumulative Impacts

Toxic Air Pollutant	Maximum Increase/Decrease	Emissions Change (tons per year)	Year	Alternative	Nonattainment or Maintenance Area (NAAQS Standard[s])
Carbon monoxide (CO)	Maximum Increase	11	2018	Alt. 5	New York, NY-NJ-CT [PM 2.5 (2006 24-hour)]
	Maximum Decrease	-4,243	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Nitrogen oxides (NO_X)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-5,507	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Particulate matter (PM2.5)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-314	2050	Alt. 5	Baton Rouge, LA [Ozone (2008 8-hour)]
Sulfur dioxide (SO_2)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-1,641	2050	Alt. 5	Marshall, WV [SO2 (2010 1-hour)]
Volatile organic compounds (VOC)	Maximum Increase	No increases are predicted for any alternatives			
	Maximum Decrease	-522	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]

4.2.2.1.2 Toxic Air Pollutants Overview

Table 4.2.2-5 summarizes the total upstream and downstream[33] emissions of toxic air pollutants from HD vehicles by alternative for each of the toxic air pollutants and analysis years. The trends for toxic air pollutant emissions across the alternatives generally show decreases for the same reasons as for criteria pollutants (*see* Section 4.2.2.1.1). Table 4.2.2-5 shows that emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde would generally remain the same or decrease from Alternative 1 to Alternative 5. Where increases occur they are small. Emissions under Alternative 4 are

[33] Downstream emissions do not include evaporative emissions from vehicle fuel systems due to modeling limitations.

slightly greater than under Alternative 3 for most pollutants and years for the same reasons as for criteria pollutants (*see* Sections 2.2 and 4.2.1.1.1). 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 efficiency requirements.

Table 4.2.2-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts

Pollutant and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
2018	5,510	5,510	5,510	5,510	5,510
2025	3,047	3,047	3,042	3,043	3,040
2040	2,105	2,100	2,075	2,088	2,082
2050	2,337	2,330	2,301	2,316	2,309
Acrolein					
2018	916	916	916	916	916
2025	463	463	463	464	464
2040	279	280	277	282	281
2050	314	314	311	316	315
Benzene					
2018	2,682	2,681	2,680	2,680	2,680
2025	1,840	1,828	1,813	1,812	1,798
2040	1,508	1,466	1,399	1,422	1,385
2050	1,668	1,620	1,540	1,567	1,526
1,3-Butadiene					
2018	508	508	508	508	508
2025	245	245	245	247	247
2040	120	122	119	125	125
2050	134	136	133	140	139
Diesel particulate matter (DPM)					
2018	124,406	124,375	124,361	124,358	124,349
2025	92,128	91,522	90,873	90,818	90,147
2040	87,353	85,055	81,719	82,569	80,672
2050	97,804	95,064	90,980	92,104	89,869
Formaldehyde					
2018	12,898	12,898	12,898	12,898	12,898
2025	7,815	7,797	7,775	7,755	7,736
2040	6,071	5,998	5,899	5,878	5,833
2050	6,829	6,742	6,619	6,600	6,548

Figure 4.2.2-4 shows toxic air pollutant emissions for each alternative in 2040, the forecast year by which a large proportion of HD vehicle VMT would be accounted for by vehicles that meet standards as set forth under the rulemaking.

Figure 4.2.2-5 summarizes the changes over time in total national emissions of toxic air pollutants from HD vehicles under the Preferred Alternative. Figures 4.2.2-4 and 4.2.2-5 indicate a consistent trend among the toxic air pollutants. Emissions decline from 2018 to 2040 due to increasingly stringent EPA regulation of emissions from vehicles and from reductions in upstream emissions from fuel production, but increase from 2040 to 2050 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 six components, consisting of two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the three HD vehicle classes covered by the rule. (Emissions associated with the tractor-trailer classes include effects of the trailer standards.) To show the relationship among these six components for toxic air pollutants, Table 4.2.2-6 breaks down the total emissions of air toxic pollutants by component for calendar year 2040.

Table 4.2.2-7 lists the net change in nationwide emissions from HD vehicles for each of the toxic air pollutants and analysis years under the action alternatives compared to the No Action Alternative. Figure 4.2.2-6 shows these changes in percentages for 2040. Together, these tables and figures show that the emissions changes compared to the No Action Alternative tend to become larger from 2018 to 2050. For each combination of pollutant and year, the emissions generally remain the same or decrease from Alternative 2 to Alternative 5, reflecting the increasing stringency of the alternatives. Acrolein and 1,3-butadiene are exceptions, having slight increases under Alternative 2, Alternative 4, and Alternative 5 in 2025, 2040, and 2050.

The differences in national emissions of toxic air pollutants among the action alternatives compared to the No Action Alternative range from less than 1 percent to 9 percent due to the interactions of the multiple factors described above in Section 4.2.2.1.1. The smaller differences are not expected to lead to measurable changes in concentrations of toxic air pollutants in the ambient air. For such small changes, the impacts of those action alternatives would be essentially equivalent. The larger differences in emissions could lead to changes in ambient pollutant concentrations.

Figure 4.2.2-4. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles for 2040 by Alternative, Cumulative Impacts

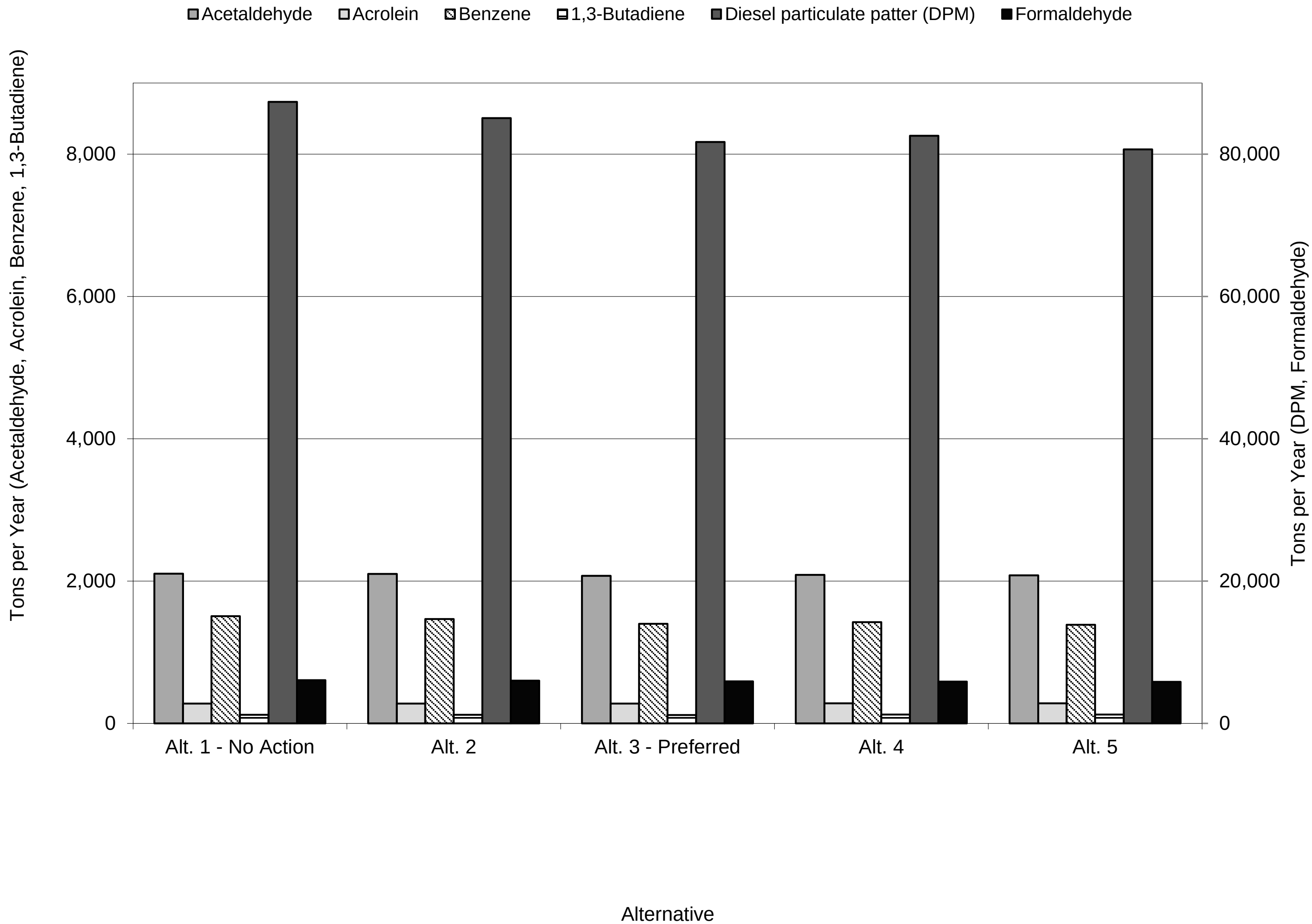


Figure 4.2.2-5. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles under the Preferred Alternative, Cumulative Impacts

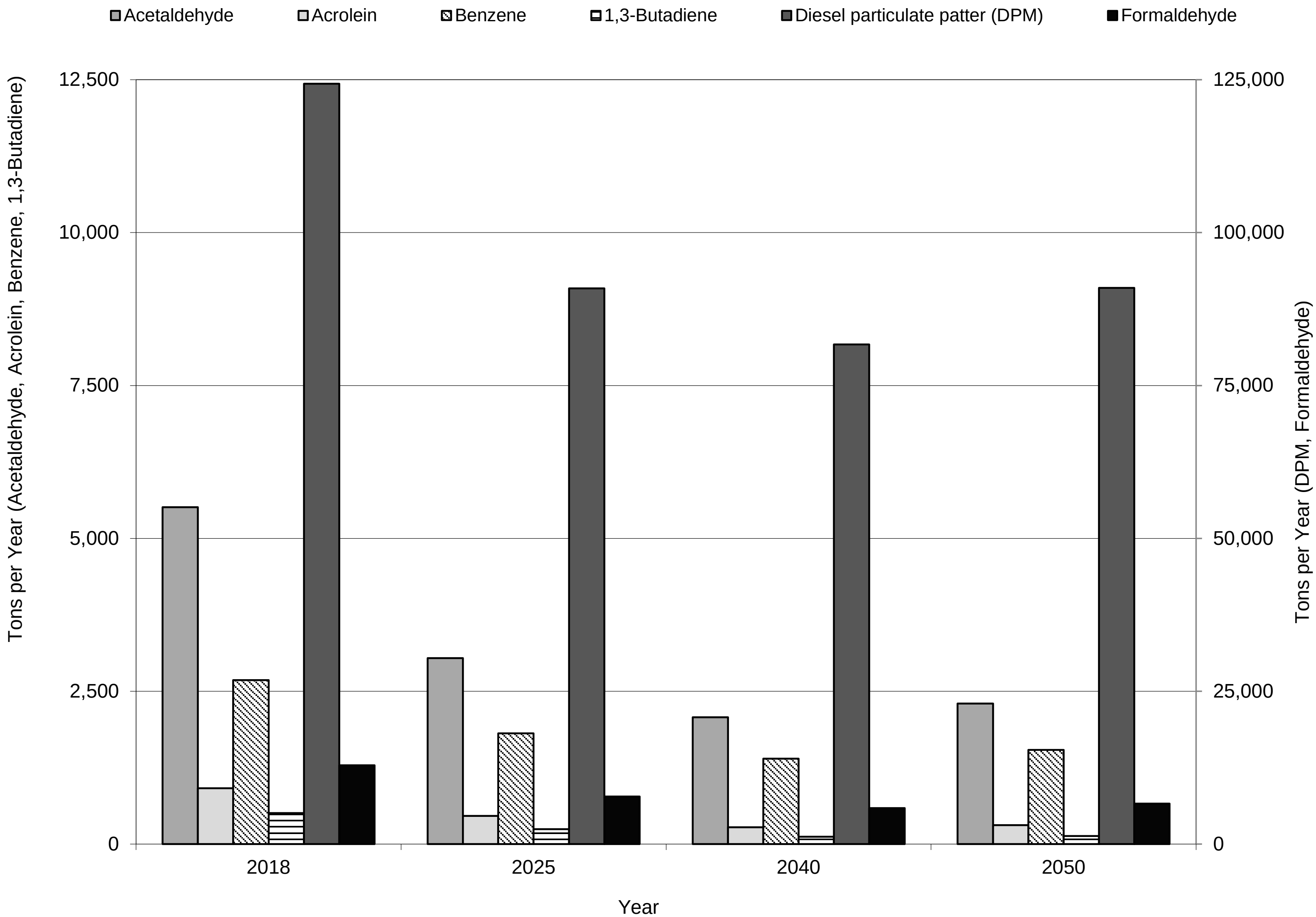


Table 4.2.2-6. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2040 from U.S. HD Vehicles, by Vehicle Type and Alternative, Cumulative Impacts

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
Classes 2b–3 Work Trucks Tailpipe	463	467	469	469	470
Classes 2b–3 Work Trucks Upstream	5	5	5	5	4
Classes –8 Vocational Vehicles Tailpipe	564	564	565	565	565
Classes 3–8 Vocational Vehicles Upstream	52	49	45	47	44
Classes 7–8 Combination Unit Tailpipe	987	984	965	975	973
Classes 7–8 Combination Unit Upstream	34	31	26	28	25
Total	2,105	2,100	2,075	2,088	2,082
Acrolein					
Classes 2b–3 Work Trucks Tailpipe	51	52	52	52	52
Classes 2b–3 Work Trucks Upstream	1	1	1	1	1
Classes 3–8 Vocational Vehicles Tailpipe	75	75	75	75	75
Classes 3–8 Vocational Vehicles Upstream	5	4	4	4	4
Classes 7–8 Combination Unit Tailpipe	143	144	142	146	146
Classes 7–8 Combination Unit Upstream	5	4	4	4	4
Total	279	280	277	282	281
Benzene					
Classes 2b–3 Work Trucks Tailpipe	403	406	409	409	410
Classes 2b–3 Work Trucks Upstream	70	65	61	61	60
Classes 3–8 Vocational Vehicles Tailpipe	330	328	325	326	324
Classes 3–8 Vocational Vehicles Upstream	179	169	155	159	151
Classes 7–8 Combination Unit Tailpipe	240	236	225	232	228
Classes 7–8 Combination Unit Upstream	285	262	224	234	213
Total	1,508	1,466	1,399	1,422	1,385
1,3-Butadiene					
Classes 2b–3 Work Trucks Tailpipe	62	63	63	63	63
Classes 2b–3 Work Trucks Upstream	1	1	1	1	1
Classes 3–8 Vocational Vehicles Tailpipe	24	24	24	24	24
Classes 3–8 Vocational Vehicles Upstream	4	4	4	4	4
Classes 7–8 Combination Unit Tailpipe	12	15	15	20	21
Classes 7–8 Combination Unit Upstream	16	15	13	13	12
Total	120	122	119	125	125
Diesel particulate matter (DPM)					
Classes 2b–3 Work Trucks Tailpipe	386	389	390	390	391
Classes 2b–3 Work Trucks Upstream	1,939	1,806	1,704	1,701	1,656
Classes 3–8 Vocational Vehicles Tailpipe	14,361	14,370	14,387	14,391	14,385
Classes 3–8 Vocational Vehicles Upstream	5,552	5,146	4,712	4,852	4,582

Pollutant and Vehicle Class	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Classes 7–8 Combination Unit Tailpipe	45,056	44,925	44,747	44,750	44,672
Classes 7–8 Combination Unit Upstream	20,059	18,420	15,779	16,485	14,987
Total	87,353	85,055	81,719	82,569	80,672
Formaldehyde					
Classes 2b–3 Work Trucks Tailpipe	978	985	989	990	990
Classes 2b–3 Work Trucks Upstream	39	36	34	34	33
Classes 3–8 Vocational Vehicles Tailpipe	1,598	1,599	1,601	1,601	1,600
Classes 3–8 Vocational Vehicles Upstream	89	83	76	78	74
Classes 7–8 Combination Unit Tailpipe	3,084	3,035	2,976	2,943	2,924
Classes 7–8 Combination Unit Upstream	283	260	222	232	211
Total	6,071	5,998	5,899	5,878	5,833

Table 4.2.2-7. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b]

Pollutant and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Acetaldehyde					
2018	0	0	0	0	0
2025	0	0	-5	-4	-7
2040	0	-5	-30	-17	-24
2050	0	-6	-36	-21	-28
Acrolein					
2018	0	0	0	0	0
2025	0	0	0	1	1
2040	0	1	-2	2	2
2050	0	1	-3	2	1
Benzene					
2018	0	-1	-2	-2	-2
2025	0	-12	-27	-28	-42
2040	0	-42	-109	-86	-123
2050	0	-48	-128	-100	-142
1,3-Butadiene					
2018	0	0	0	0	0
2025	0	1	0	2	3
2040	0	2	0	5	5
2050	0	2	-1	6	5
Diesel particulate matter (DPM)					
2018	0	-31	-45	-48	-58
2025	0	-606	-1,255	-1,310	-1,981
2040	0	-2,297	-5,634	-4,784	-6,680
2050	0	-2,739	-6,824	-5,700	-7,935
Formaldehyde					
2018	0	0	0	0	0
2025	0	-18	-40	-60	-79
2040	0	-73	-172	-192	-238
2050	0	-87	-209	-229	-281

Notes:

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 other alternatives are compared.

Figure 4.2.2-6 (a)–(f). Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. HD Vehicles for 2040 by Action Alternative Compared to the No Action Alternative, Cumulative Impacts

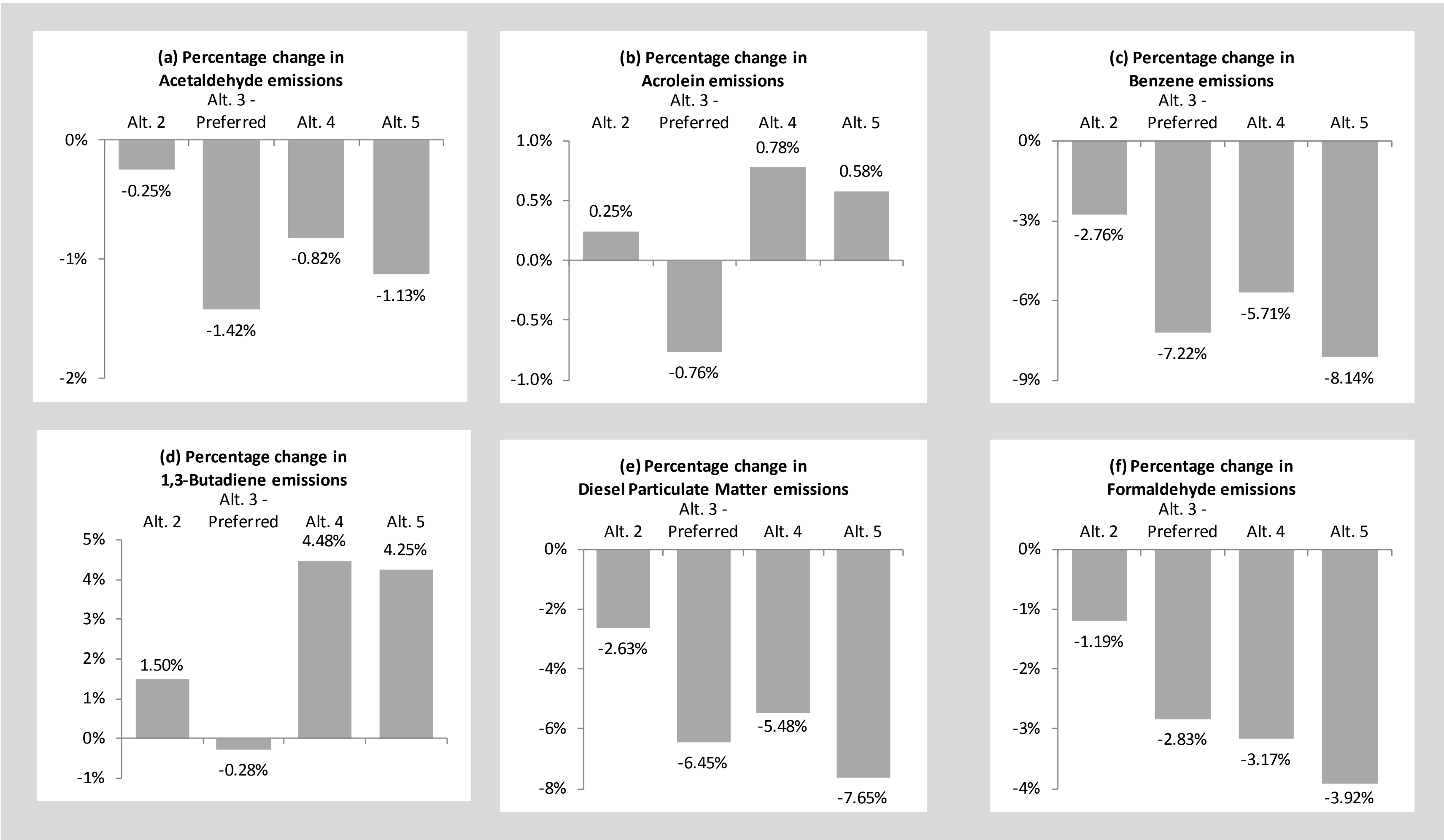


Table 4.2.2-8 summarizes the air toxics analysis results by nonattainment area.[34] Tables in Appendix A list the estimated emissions changes for each nonattainment area. For acetaldehyde and formaldehyde, Appendix A indicates that most nonattainment areas experience increases in emissions in 2018 under all the action alternatives, but decreases in 2025, 2040, and 2050 under all the action alternatives (except that for acetaldehyde most nonattainment areas experience increases in all analysis years under Alternative 2). For acrolein and 1,3-butadiene, most nonattainment areas experience increases in emissions in all analysis years under all the action alternatives. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under all the action alternatives. For DPM, most nonattainment areas experience decreases in emissions in 2018, 2040, and 2050 under all the action alternatives, but increases in 2025 under all the action alternatives.

Table 4.2.2-8. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. HD Vehicles, Across All Nonattainment or Maintenance Areas, Alternatives, and Years, Cumulative Impacts

Toxic Air Pollutant	Max. Increase/ Decrease	Emissions Change (tons per year)	Year	Alt.	Nonattainment or Maintenance Area (NAAQS Standard[s])
Acetaldehyde	Maximum Increase	0.1	2025	Alt. 2	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (2008 8-hour)]
	Maximum Decrease	-6	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Acrolein	Maximum Increase	0.2	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (2008 8-hour)]
	Maximum Decrease	-2	2050	Alt. 5	AQCR 131: Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties (Minneapolis-St. Paul), MN [SO2 (1971 24-hour/Annual)]
Benzene	Maximum Increase	0	No increases are predicted for any alternatives		
	Maximum Decrease	-3	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
1,3-Butadiene	Maximum Increase	0.5	2050	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (2008 8-hour)]
	Maximum Decrease	-2	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
Diesel particulate matter (DPM)	Maximum Increase	2	2025	Alt. 4	Dallas-Fort Worth, TX [Ozone (2008 8-hour)]
	Maximum Decrease	-408	2050	Alt. 5	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
Formaldehyde	Maximum Increase	0.03	2018	Alt. 5	New York-N. New Jersey-Long Island, NY-NJ-CT [Ozone (2008 8-hour)]
	Maximum Decrease	-18	2050	Alt. 5	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]

[34] EPA has not established NAAQS for airborne toxics. Therefore, none of these areas is classified as a nonattainment area as a result of airborne toxics emissions. Toxic air pollutant emissions data for nonattainment areas are provided for information only.

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 4.2.2-9). As described in Section 4.1.2.7.2, the changes in PM mortality shown in these tables are measured in several ways; benefits are measured under the Krewski methodology and the Lepeule methodology and at discount rates of 3 and 7 percent (*see* Section 4.1.2.7.2). While the number of PM mortalities varies between the two methods, the percent change in mortality across alternatives and years is equal. The health benefits across all outcomes generally remain the same or increase from Alternative 2 to Alternative 5 and from near-future (2018) to later years (2050). For each combination of pollutant and year, the health benefits generally increase from Alternative 2 to Alternative 5, reflecting the increasing stringency of the alternatives. Alternative 4 is an exception to this pattern, having fewer health benefits in 2040 and 2050 than Alternative 3 for the reasons discussed in Sections 2.2 and 4.2.1.1.1.

Table 4.2.2-9. Nationwide Changes in Health Outcomes (cases per year) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b]

Outcome and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Premature mortality – Krewski et al. (2009)					
2018	0	-2	-3	-4	-4
2025	0	-60	-120	-135	-192
2040	0	-228	-541	-493	-663
2050	0	-271	-653	-584	-784
Premature mortality – Lepeule et al. (2012)					
2018	0	-5	-7	-8	-10
2025	0	-138	-274	-310	-440
2040	0	-511	-1,211	-1,104	-1,484
2050	0	-606	-1,462	-1,309	-1,756
Acute bronchitis					
2018	0	-4	-5	-6	-7
2025	0	-97	-193	-217	-309
2040	0	-340	-806	-734	-987
2050	0	-404	-973	-871	-1,168
Work-loss days					
2018	0	-322	-461	-514	-621
2025	0	-8,119	-16,145	-18,209	-25,903
2040	0	-28,452	-67,474	-61,269	-82,476
2050	0	-33,777	-81,433	-72,674	-97,608
Emergency room visits – respiratory					
2018	0	-1	-2	-2	-2
2025	0	-31	-61	-69	-98
2040	0	-111	-262	-240	-322
2050	0	-132	-317	-285	-381

[a] Incidence estimates are rounded to the nearest whole number.

[b] Negative changes indicate fewer health impacts; positive changes indicate additional health impacts.

[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.

The monetized health benefits follow similar trends to the changes in health outcomes. Table 4.2.2-10 lists the corresponding monetized health benefits under the action alternatives compared to the No Action Alternative. Monetized health benefits are measured in several ways; benefits are measured under the Krewski methodology and the Lepeule methodology and at discount rates of 3 and 7 percent (*see* Section 4.1.2.7.2). Under each action alternative, the monetized health benefits increase from 2018 to 2050. In each analysis year, the monetized health benefits of each action alternative increase from Alternative 2 (least stringent) to Alternative 5 (most stringent). Alternative 4 is an exception, having lower monetized health benefits in 2040 and 2050 than Alternative 3 for the reasons discussed in Sections 2.2 and 4.2.1.1.1.

Table 4.2.2-10. Nationwide Monetized Health Benefits (U.S. million dollars per year, 2013$) from Criteria Pollutant Emissions from U.S. HD Vehicles by Alternative, Cumulative Impacts[a,b]

Rate and Year	Alt. 1 – No Action[c]	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
3-Percent Discount Rate					
Mortality (ages 30 and older) and Morbidity, Krewski et al. (2009)					
2018	$0	$24	$35	$39	$47
2025	$0	$645	$1,283	$1,450	$2,062
2040	$0	$2,621	$6,215	$5,652	$7,605
2050	$0	$3,112	$7,501	$6,705	$9,000
Mortality (ages 30 and older) and Morbidity, Lepeule et al. (2012)					
2018	$0	$55	$79	$88	$107
2025	$0	$1,458	$2,899	$3,276	$4,657
2040	$0	$5,843	$13,856	$12,618	$16,968
2050	$0	$6,937	$16,723	$14,968	$20,081
7-Percent Discount Rate					
Mortality (ages 30 and older) and Morbidity, Krewski et al. (2009)					
2018	$0	$22	$32	$35	$42
2025	$0	$579	$1,151	$1,301	$1,850
2040	$0	$2,345	$5,559	$5,058	$6,804
2050	$0	$2,784	$6,710	$6,000	$8,052
Mortality (ages 30 and older) and Morbidity, Lepeule et al. (2012)					
2018	$0	$49	$70	$78	$94
2025	$0	$1,310	$2,606	$2,943	$4,184
2040	$0	$5,292	$12,546	$11,428	$15,364
2050	$0	$6,284	$15,143	$13,557	$18,184

Notes:

[a] Monetized health benefits are rounded to the nearest whole number.

[b] Positive changes indicate greater benefits and fewer health impacts; negative changes indicate fewer benefits and additional health impacts.

[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.

Sections 4.2.2.2 through 4.2.2.5 describe the results of the analysis of emissions for Alternatives 1 through 5 in more detail. The emissions changes from one alternative to the next compared to the No

Action Alternative generally become larger between Alternative 2 and Alternative 5, consistent with increases in overall fuel efficiency. Exceptions to this are discussed in these sections.

4.2.2.2 Alternative 1 - No Action

4.2.2.2.1 Criteria Pollutants

The No Action Alternative generally assumes no market-based gains in new HD vehicle fuel efficiency after 2018. Current trends in the levels of criteria pollutant emissions from vehicles would continue under the No Action Alternative, with emissions of CO, NO_X, PM2.5, and VOCs continuing to decline due to the EPA emissions standards (*see* Section 4.1), despite a growth in total VMT from 2018 to 2040, but increasing from 2040 to 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.2-1 and Figure 4.2.2-2). Emissions of SO_2 under the No Action Alternative are predicted to increase from 2018 to 2050 because declines due to market-based gains in new vehicle HD vehicle fuel efficiency are more than offset by growth in VMT beginning before 2018. 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).

Emissions of CO (except in 2018), NO_X, PM2.5, SO_2, and VOCs under the No Action Alternative are greater than emissions under all of the action alternatives. Emissions of CO in 2018 under the No Action Alternative would be less than emissions under all of the action alternatives. Changes in emissions of all criteria pollutants are generally greatest in 2050 under Alternative 5 compared to the No Action Alternative, in which emissions range up to 24 percent less than under the No Action Alternative.

4.2.2.2.2 Toxic Air Pollutants

EPA regulates toxic air pollutants from motor vehicles through vehicle emissions 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. Emissions would continue to decline in early years due to the EPA emissions standards (*see* Section 4.1.1) despite a growth in total VMT, reaching a minimum in 2040, but increasing in 2050 because continued growth in total VMT during that period overwhelms the initial decreases (*see* Table 4.2.2-5 and Figure 4.2.2-5). The No Action Alternative would not change the current fuel efficiency standards for HD vehicles 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 Table 4.2.2-5.

Table 4.2.2-5 shows that emissions of acetaldehyde and formaldehyde under the No Action Alternative are the same as emissions under all of the action alternatives in 2018, and are greater than emissions under all of the action alternatives in 2025, 2040, and 2050. Emissions of acrolein and 1,3-butadiene under the No Action Alternative are the same as or less than emissions under all of the action alternatives, except for the Preferred Alternative in 2040 and 2050. Emissions of benzene and DPM under the No Action Alternative are greater than emissions under all of the action alternatives.

Compared to the No Action alternative, changes in emissions of toxic air pollutants are greatest in 2040 (for acrolein and 1,3-butadiene) and 2050 (for acetaldehyde, benzene, DPM, and formaldehyde), and range from an increase of 4 percent (under Alternative 4) to a decrease of 9 percent (under Alternative 5).

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 decreasing initially and then increasing to 2050 due to growth in total VMT, which more than offsets reductions due to the EPA vehicle emissions standards (*see* Section 4.1.1). The human health-related trends would continue (*see* Tables 4.2.2-9 and 4.2.2-10). The No Action Alternative would not result in any additional increase or decrease in human health effects throughout the United States.

4.2.2.3 Alternative 2

4.2.2.3.1 Criteria Pollutants

Table 4.2.2-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 2 compared to the No Action Alternative and the action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2040. Under Alternative 2, nationwide emissions of all criteria pollutants decrease compared to the No Action Alternative (except for CO in 2018). Alternative 2 is the least stringent of all the action alternatives, and the emissions reductions under Alternative 2 are less than those under the Preferred Alternative, Alternative 4, and Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 2 compared to the No Action Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 2, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in CO emissions in 2025, 2040, and 2050. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years. Tables in Appendix A list the emissions changes for each nonattainment area.

4.2.2.3.2 Toxic Air Pollutants

Table 4.2.2-7 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. In 2018, compared to the No Action Alternative, Alternative 2 would result in the same or increased emissions of acetaldehyde, acrolein, 1,3-butadiene, and formaldehyde. In 2025, 2040, and 2050, Alternative 2 would result in the same or increased emissions of acrolein and 1,3-butadiene, but decreased emissions of acetaldehyde and formaldehyde. Alternative 2 would result in decreased emissions of benzene and DPM in all analysis years. Alternative 2 would result in the same or higher emissions than would the Preferred Alternative, Alternative 4, or Alternative 5 for most pollutants and years. Alternative 2 would result in lower emissions than would Alternative 4 and Alternative 5 for acrolein and 1,3-butadiene in 2025, 2040, and 2050.

At the national level, emissions of all toxic air pollutants could decrease under Alternative 2 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde, acrolein, and 1,3-butadiene, most nonattainment areas would experience increases in emissions in all analysis years under Alternative 2. For benzene and DPM (except for DPM in 2025), most nonattainment areas experience decreases in emissions in all analysis years under

Alternative 2. For formaldehyde, most nonattainment areas would experience increases in emissions in 2018 under Alternative 2, but decreases in 2025, 2040 and 2050 (*see* Appendix A).

4.2.2.3.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 2 compared to the No Action Alternative (*see* Table 4.2.2-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.2-10, the monetized health impacts under Alternative 2 would range from a minimum benefit of $22 million per year to a maximum benefit of approximately $6.9 billion per year, depending on methodology, discount rate, and year. The monetized health benefits under Alternative 2 are less than those under the other action alternatives.

4.2.2.4 Alternative 3 – Preferred Alternative

4.2.2.4.1 Criteria Pollutants

Table 4.2.2-3 shows the changes in nationwide emissions of criteria pollutants under the Preferred Alternative 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 the Preferred Alternative by year. Under this alternative, emissions of all criteria pollutants decrease compared to the No Action Alternative (except for CO in 2018). This alternative reduces emissions more than Alternative 2. Emissions under the Preferred Alternative are less than under Alternative 2, but greater than under Alternative 4 (except for CO in 2018, and PM2.5, SO_2, and VOCs in 2040 and 2050) and Alternative 5.

At the national level, emissions of all criteria air pollutants could decrease under the Preferred Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under the Preferred Alternative, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2040, and 2050. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years (*see* Appendix A).

4.2.2.4.2 Toxic Air Pollutants

Table 4.2.2-7 shows the changes in nationwide emissions of toxic air pollutants under the Preferred Alternative compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-5 shows toxic pollutant emissions under the Preferred Alternative by year. Figure 4.2.2-6 shows these changes in percentage terms for 2040. Compared to the No Action Alternative, the Preferred Alternative would result in the same or reduced emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, DPM, and formaldehyde. The Preferred Alternative would result in the same or lower emissions than would Alternative 2. The Preferred Alternative would result in the same or lower emissions than would Alternative 4 for acetaldehyde, acrolein, benzene (in 2018, 2040, and 2050), 1,3-butadiene, DPM (in 2040 and 2050), and formaldehyde (in 2018), but higher emissions than would Alternative 4 for benzene (in 2025), DPM (in 2018 and 2025), and formaldehyde (in 2025, 2040, and 2050). The Preferred Alternative would result in the same or lower emissions than would Alternative 5 for acetaldehyde (in 2018, 2040, and 2050), acrolein, benzene (in 2018), 1,3-butadiene, and formaldehyde (in 2018), but higher emissions than would Alternative 5 for acetaldehyde (in 2025), benzene (in 2025, 2040, and 2050), DPM, and formaldehyde (in 2025, 2040, and 2050).

At the national level, emissions of all toxic air pollutants could decrease under the Preferred Alternative because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under the Preferred Alternative, but decreases in 2025, 2040, and 2050. For acrolein, most nonattainment areas experience increases in emissions in 2018 and 2025 under the Preferred Alternative, but decreases in 2040 and 2050. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under the Preferred Alternative. For 1,3-butadiene, most nonattainment areas experience increases in emissions in all analysis years under the Preferred Alternative. For DPM, most nonattainment areas experience decreases in emissions in 2018, 2040, and 2050 under the Preferred Alternative, but increases in 2025 (*see* Appendix A).

4.2.2.4.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under the Preferred Alternative compared to the No Action Alternative (*see* Table 4.2.2-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.2-10, the monetized health impacts under the Preferred Alternative would range from a minimum benefit of $32 million per year to a maximum benefit of approximately $16.7 billion per year, depending on methodology, discount rate, and year. The monetized health benefits under the Preferred Alternative are greater than those under Alternative 2 but less than those under Alternative 4 (except in 2040 and 2050). In 2040 and 2050, the monetized health benefits under the Preferred Alternative are greater than those under Alternative 4. The monetized health benefits under the Preferred Alternative are less than those under Alternative 5.

4.2.2.5 Alternative 4

4.2.2.5.1 Criteria Pollutants

Table 4.2.2-3 shows 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 this alternative, emissions of all criteria pollutants decrease compared to the No Action Alternative (except for CO in 2018). This alternative reduces emissions more than Alternative 2 and the Preferred Alternative (except that CO emissions under Alternative 4 are slightly higher than under the Preferred Alternative in 2018 and emissions of PM2.5, SO_2, and VOC under Alternative 4 are higher than under the Preferred Alternative in 2040 and 2050). Emissions under Alternative 4 are greater than under Alternative 5 (except for CO in 2018).

At the national level, emissions of all criteria air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 4, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2040, and 2050. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years (*see* Appendix A).

4.2.2.5.2 Toxic Air Pollutants

Table 4.2.2-7 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 percentage terms for 2040. Compared to the No Action Alternative, Alternative 4 would result in the same or reduced emissions of acetaldehyde, acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions of acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Alternative 4 would result in the same or lower emissions than would Alternative 2 for acetaldehyde, acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions than would Alternative 2 for acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Alternative 4 would result in the same or lower emissions than would the Preferred Alternative for acetaldehyde (in 2018), acrolein (in 2018), benzene (in 2018 and 2025), 1,3-butadiene (in 2018), DPM (in 2018 and 2025), and formaldehyde, but higher emissions than would the Preferred Alternative for acetaldehyde (in 2025, 2040, and 2050), acrolein (in 2025, 2040, and 2050), benzene (in 2040 and 2050), 1,3-butadiene (in 2025, 2040, and 2050), and DPM (in 2040 and 2050). Alternative 4 would result in the same or lower emissions than would Alternative 5 for acetaldehyde (in 2018), acrolein (in 2018 and 2025), 1,3-butadiene (in 2018, 2025, and 2040), and formaldehyde (in 2018), but higher emissions than would Alternative 5 for acetaldehyde (in 2025, 2040, and 2050), acrolein (in 2040 and 2050), benzene, 1,3-butadiene (in 2050), DPM, and formaldehyde (in 2025, 2040, and 2050).

At the national level, as with the less-stringent alternatives, emissions of all toxic air pollutants could decrease under Alternative 4 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 4, but decreases in 2025, 2040, and 2050. For acrolein and 1,3-butadiene, most nonattainment areas experience increases in emissions in all analysis years under Alternative 4. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 4. For DPM, most nonattainment areas experience increases in emissions in 2025 under Alternative 4, but decreases in 2018, 2040, and 2050 (*see* Appendix A).

4.2.2.5.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 4 compared to the No Action Alternative (*see* Table 4.2.2-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.2-10, the monetized health impacts under Alternative 4 would range from a minimum benefit of $35 million per year to a maximum benefit of approximately $15.0 billion per year, depending on methodology, discount rate, and year. The monetized benefits under Alternative 4 are greater than those under Alternative 2 in all analysis years, and greater than those under the Preferred Alternative in 2018 and 2025, but less than those under the Preferred Alternative in 2040 and 2050, and less than those under Alternative 5 in all analysis years.

4.2.2.6 Alternative 5

4.2.2.6.1 Criteria Pollutants

Table 4.2.2-3 shows the changes in nationwide emissions of criteria pollutants under Alternative 5 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-3 shows these changes in percentages for 2040. Under this alternative, emissions of all criteria pollutants decrease compared to the No Action Alternative (except for CO in 2018). This alternative reduces emissions (except for CO in 2018) more than Alternative 2, the Preferred Alternative, and Alternative 4. For CO in 2018, emissions under Alternative 5 would be greater than under Alternative 2, the Preferred Alternative, and Alternative 4.

At the national level, emissions of all criteria air pollutants could decrease under Alternative 5 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of criteria pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Under Alternative 5, most nonattainment areas would experience increases in emissions of CO in 2018, but decreases in 2025, 2040, and 2050. For NO_X, PM2.5, SO_2, and VOCs, most nonattainment areas would experience decreases in emissions in all analysis years (*see* Appendix A).

4.2.2.6.2 Toxic Air Pollutants

Table 4.2.2-7 shows the changes in nationwide emissions of toxic air pollutants under Alternative 5 compared to the No Action Alternative and the other action alternatives. Figure 4.2.2-6 shows these changes in percentage terms for 2040. Compared to the No Action Alternative, Alternative 5 would result in the same or reduced emissions of acetaldehyde, acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions of acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Compared to Alternative 2, Alternative 5 would result in the same or lower emissions for acetaldehyde, acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions of acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Compared to the Preferred Alternative, Alternative 5 would result in the same or lower emissions of acetaldehyde (in 2018 and 2025), acrolein (in 2018), benzene, 1,3-butadiene (in 2018), DPM, and formaldehyde, but higher emissions of acetaldehyde (in 2040 and 2050), acrolein (in 2025, 2040, and 2050) and 1,3-butadiene (in 2025, 2040, and 2050). Compared to Alternative 4, Alternative 5 would result in the same or lower emissions of all toxic air pollutants.

At the national level, as with the less-stringent alternatives, emissions of all toxic air pollutants could decrease under Alternative 5 because the increases in vehicle emissions due to the rebound effect are more than offset by reductions in upstream emissions of toxic air pollutants due to improved fuel efficiency and the resulting decline in the volume of fuel refined and distributed. However, the decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. For acetaldehyde and formaldehyde, most nonattainment areas experience increases in emissions in 2018 under Alternative 5, but decreases in 2025, 2040, and 2050. For acrolein and 1,3-butadiene, most nonattainment areas experience increases in emissions in all analysis years under Alternative 5. For benzene, most nonattainment areas experience decreases in emissions in all analysis years under Alternative 5. For DPM, most nonattainment areas experience increases in emissions in 2025 under Alternative 5, but decreases in 2018, 2040, and 2050 (*see* Appendix A).

4.2.2.6.3 Health Outcomes and Monetized Benefits

Adverse health effects nationwide would be reduced under Alternative 5 compared to the No Action Alternative (*see* Table 4.2.2-9). These health benefits would increase greatly from 2018 to 2050. As shown in Table 4.2.2-10, the monetized health impacts under Alternative 5 would range from a minimum benefit of $42 million per year to a maximum benefit of approximately $20.1 billion per year, depending on methodology, discount rate, and year. The monetized benefits under Alternative 5 are greater than those under Alternative 2, the Preferred Alternative, and Alternative 4.

CHAPTER 5 GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

This section describes how the Final Action and alternatives would affect the anticipated pace and extent of future changes in global climate. The Council on Environmental Quality (CEQ) released final guidance on consideration of the effects of climate change and GHG emissions under NEPA in August 2016. This guidance builds off of a 2010 draft guidance and 2014 revised draft guidance. One of the key matters about which federal agencies must use their own judgment is when they determine how to describe the potential differences between direct and indirect climate change-related impacts of a proposed action and the cumulative impacts associated with a proposed action.

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 Final Action and alternatives (assumed to remain in place after 2027 at the level of the Phase 2 standards set forth by the agency), including Alternative 1 (No Action Alternative) and Alternatives 2 through 5 (the action alternatives). The Final Action and alternatives would affect fuel consumption and emissions attributable to commercial medium- and heavy-duty on-highway vehicles and work trucks, hereinafter referred to collectively as *HD vehicles*, into the future. Results in this chapter are shown through 2100, the end of the analytical period for this section. The discussion of consequences of the Final Action and alternatives focuses on GHG emissions and their impacts on the climate system (i.e., atmospheric CO_2 concentrations, temperature, sea level, and precipitation).

The cumulative impacts analysis addresses the effects of the Final Action and alternatives together with those of other past, present, and reasonably foreseeable future actions. These reasonably foreseeable future actions, beyond those resulting directly or indirectly from the Final Action and alternatives, would have additional impacts on fuel consumption and emissions attributable to HD 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. HD 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 potential direct, indirect, and cumulative environmental impacts of the Final Action and alternatives that NHTSA considered.
- **Section 5.5:** Qualitatively describes the potential cumulative impacts of climate change on key natural and human resources.
- **Section 5.6:** Qualitatively describes the potential cumulative non-climate effects of CO_2.

5.1 Introduction

This EIS draws primarily on newly released panel-reviewed synthesis and assessment reports from the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Global Change Research Program (GCRP), supplemented with past reports from the U.S. Climate Change Science Program (CCSP), the National Research Council, and the Arctic Council. It also cites EPA's *Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under the Clean Air Act* (EPA 2009), which relied heavily on past 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.

To provide the most current review of climate change science, this EIS also draws on peer-reviewed panel reports and literature that have been published since the release of the IPCC and the GCRP panel-reviewed reports. 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, as well as NHTSA's consideration of other studies that demonstrate the potential impacts of climate change on health, society, and the environment, is provided to help inform the public and decisionmakers and is consistent with NHTSA's approach in its EISs for the MY 2012–2016 CAFE standards, MY 2014–2018 HD vehicle standards, and MY 2017–2025 CAFE standards.

5.1.1 Uncertainty within the IPCC Framework

As with all other environmental impacts, assessing climate change impacts involves uncertainty. The CEQ regulations in section 1502.22 require agencies to make clear for potentially significant adverse environmental impacts any incomplete or unavailable information regarding that impact. Similarly, given the global importance of climate change and the need to communicate uncertainty to a variety of decisionmakers, IPCC has focused considerable attention on developing a systematic approach to characterize and communicate this information. In this EIS, NHTSA uses the system developed by IPCC to describe uncertainty associated with various climate change impacts. Consequently, the meanings of these IPCC terms, as further explained below, is different from the language used to describe uncertainty elsewhere in the EIS.

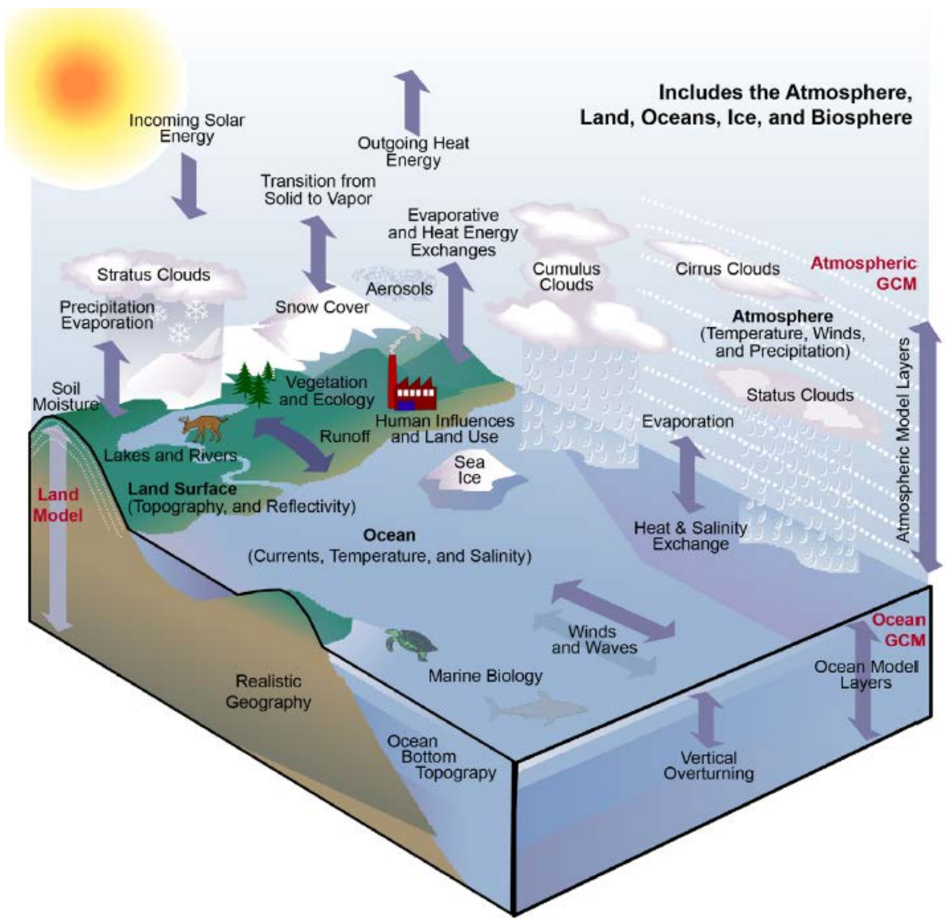
The IPCC reports communicate uncertainty and confidence bounds using commonly understood, but carefully defined, words in italics, such as *likely* and *very likely*, to represent likelihood of occurrence. The *IPCC Working Group I (WG1) Fifth Assessment Report (AR5) Summary for Policymakers* (IPCC 2013a) briefly explains this convention. The IPCC Guidance Notes for Lead Authors of the *IPCC AR5 on Addressing Uncertainties* (IPCC 2010) 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. The IPCC WG1 AR5: The Physical Science Basis notes that the two primary uncertainties with climate modeling are model uncertainties and scenario uncertainties.

- **Model uncertainties:** Occur when a climate model might not accurately represent complex phenomena within the climate system (*see* Figure 5.1.1-1 for a sample of processes generally represented in climate models). For some processes, the scientific understanding could be limited regarding how to use a climate model to "simulate" processes within the climate system. Model uncertainties can be differentiated into parametric and structural uncertainties. Parametric uncertainties are a result of uncertainties in the values of model parameters (e.g., the interaction of particles in Earth's atmosphere with water vapor to trigger cloud formation is represented by a parameterization, as opposed to including the very fine-scaled physics within the climate model). Structural uncertainties are the uncertainties that result from incomplete scientific understanding of the processes.
- **Scenario uncertainties:** Arise because of uncertainty in projecting future GHG emissions, concentrations, and forcings.

As stated in the *IPCC WG1 AR5*, these types of uncertainties are described by using two metrics for communicating the degree of certainty: (1) confidence in the validity of finding, expressed qualitatively, and (2) quantified measures of uncertainties, expressed probabilistically.

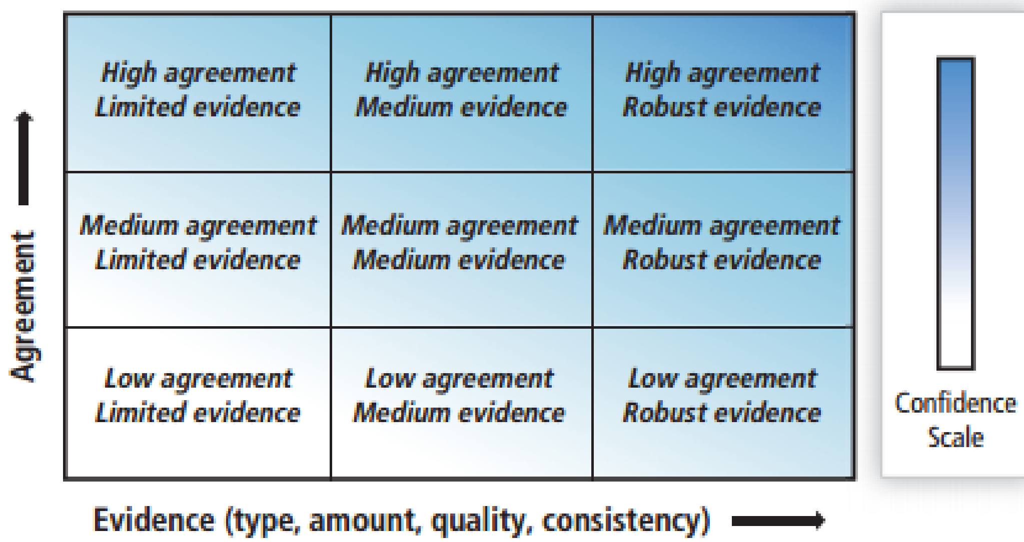
Figure 5.1.1-1. Some of the Climate System Processes Included in Climate Models



Source: GCRP 2014.
GCM = general circulation model

The confidence levels synthesize the judgments about the validity of the findings, determined through evaluation of the evidence and the degree of scientific agreement. For qualitatively expressed confidence, the range in assigning confidence is from *very low* to *very high*, with higher confidence levels assigned to findings that are supported by high scientific agreement. For quantitatively expressed confidence, the range in assigning confidence is from *exceptionally unlikely* to *virtually certain*, with higher confidence representing findings supported by robust evidence. Figure 5.1.1-2 shows the degree of confidence for both metrics. Confidence increases diagonally from bottom left to top right.

Figure 5.1.1-2. The Basis for the Confidence Level Given as a Combination of Evidence and Agreement



Source: IPCC 2013b.

Table 5.1.1-1 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). The IPCC has defined the list of terms to be used to indicate the assessed likelihood.

Table 5.1.1-1. Standard Terms Used to Define the Likelihood of an Occurrence of a Climate-related Event

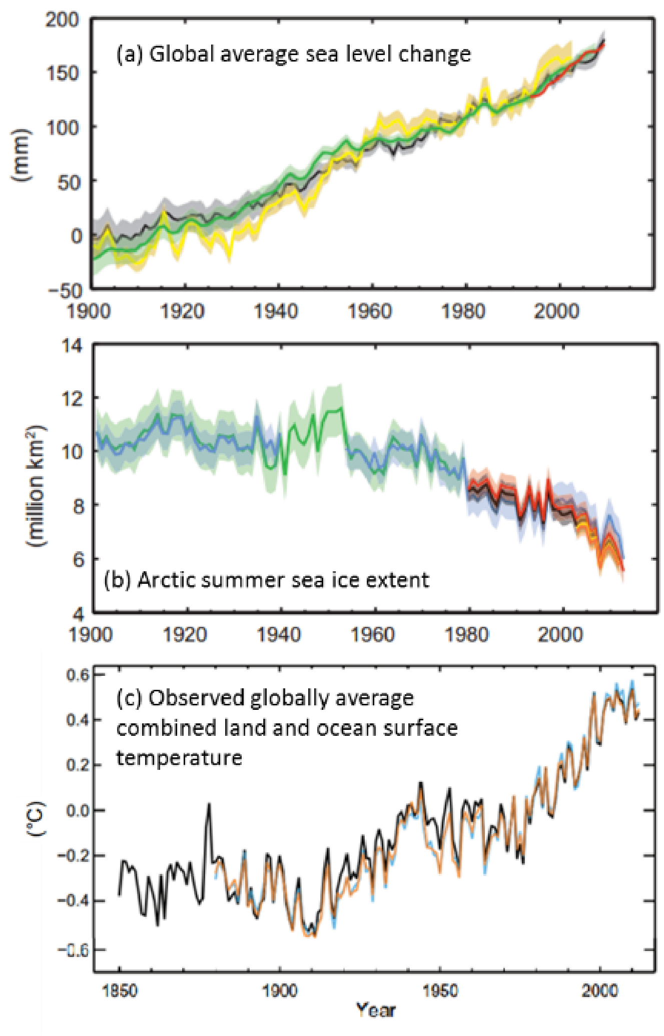
Likelihood Terminology	Likelihood of the Occurrence/Outcome
Virtually certain	99%–100% probability
Very likely	90%–100% probability
Likely	66%–100% probability
About as likely as not	33%–66% probability
Unlikely	0%–33% probability
Very unlikely	0%–10% probability
Exceptionally unlikely	0%–1% probability

Source: IPCC 2013b.

5.1.2 Climate Change and Its Causes

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. From 1880 to 2012, Earth's global average surface temperature rose by more than 0.8°C (1.4°F) (IPCC 2013a, GCRP 2014). Global mean sea level rose about 19 centimeters (7.5 inches) from 1901 to 2010. From 1901 to 2010, sea levels increased at a rate of 1.7 millimeters (0.07 inch) per year. The rate at the end of this period was much higher, at approximately 3.2 millimeters (0.13 inch) per year from 1993 to 2010 (IPCC 2013a). The annual mean Arctic sea-ice cover has been decreasing at a *very likely* rate of approximately 3.5 to 4.1 percent per decade since 1979, with the summer experiencing a *very likely* faster decrease of 9.4 to 13.6 percent per decade. There is *high* confidence that the extent and volume of mountain glaciers and the Northern Hemisphere snow cover have been decreasing (IPCC 2014a). Figure 5.1.2-1 shows changes in sea level, Arctic sea ice, and surface temperatures.

Figure 5.1.2-1. Changes in Sea Level, Arctic Summer Sea-Ice Extent, and Surface Temperature



Source: IPCC 2013a.

Note: Each line on the graphs above depicts mean values of one data set. Multiple data sets are displayed in each graph using different colors. Shaded areas in the graphs depict uncertainty in the data sets.

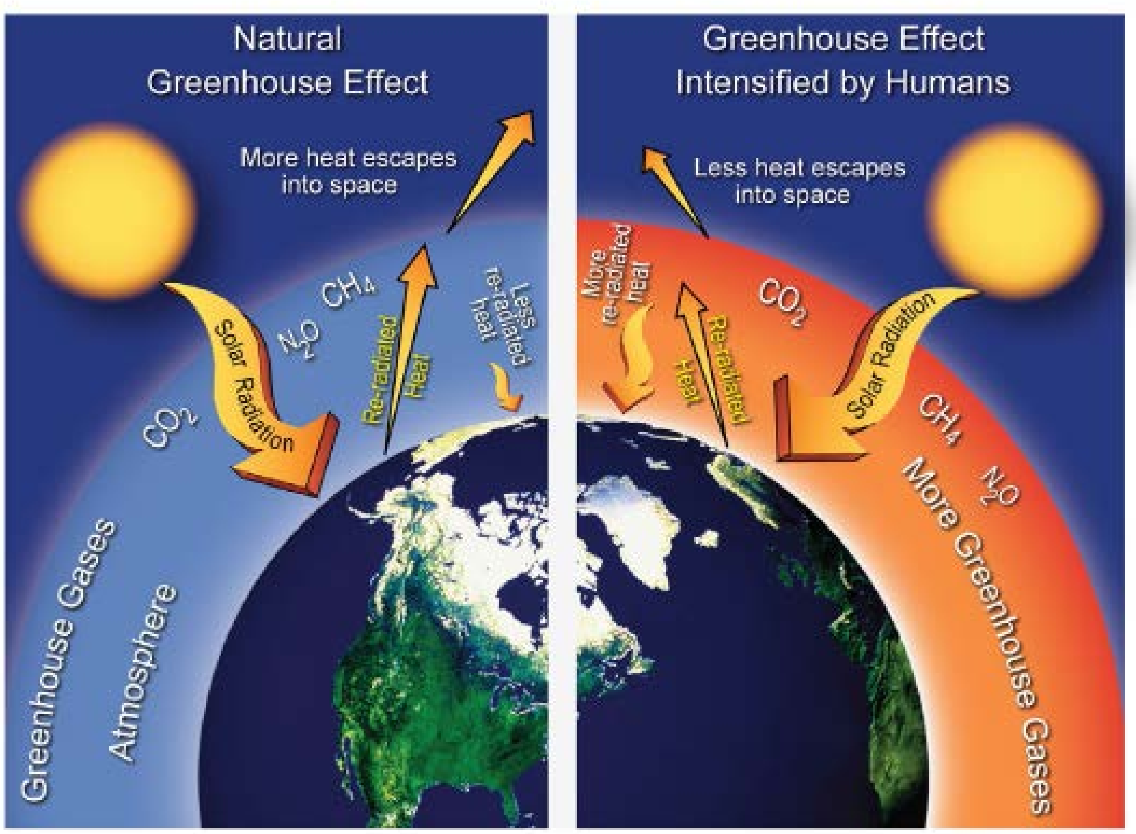
mm = millimeters; km^2 = kilometers squared; °C = degrees Celsius.

For the United States (GCRP 2014):

- U.S. annual average temperature has increased by 1.3°F to 1.9°F since 1895, and most of this increase has occurred since 1970.
- There is ample evidence that sea-surface temperatures have risen throughout the North Atlantic and Pacific Ocean regions by more than 0.9°F since 1900.
- U.S. average annual precipitation has increased by approximately 5 percent, but some areas have had increases greater than the national averages, and some areas have had decreases.

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 4 to 12 miles above the surface), absorb heat energy emitted by Earth's surface and lower atmosphere, and reradiate much of it back to Earth's surface, thereby causing warming. This process, known as the *greenhouse effect*, is responsible for maintaining surface temperatures that are warm enough to sustain life (*see* Figure 5.1.2-2). 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 (*see* Figure 5.1.2-2). Climate simulations support this finding by demonstrating that the warming experienced over the past century requires the inclusion of both natural GHGs and other climatic forcers (e.g., solar activity) as well as manmade climate forcers.

Figure 5.1.2-2. Human Influence on the Greenhouse Effect



Source: GCRP 2014.
CO_2 = carbon dioxide; N_2O = nitrous oxide; CH_4 = methane.

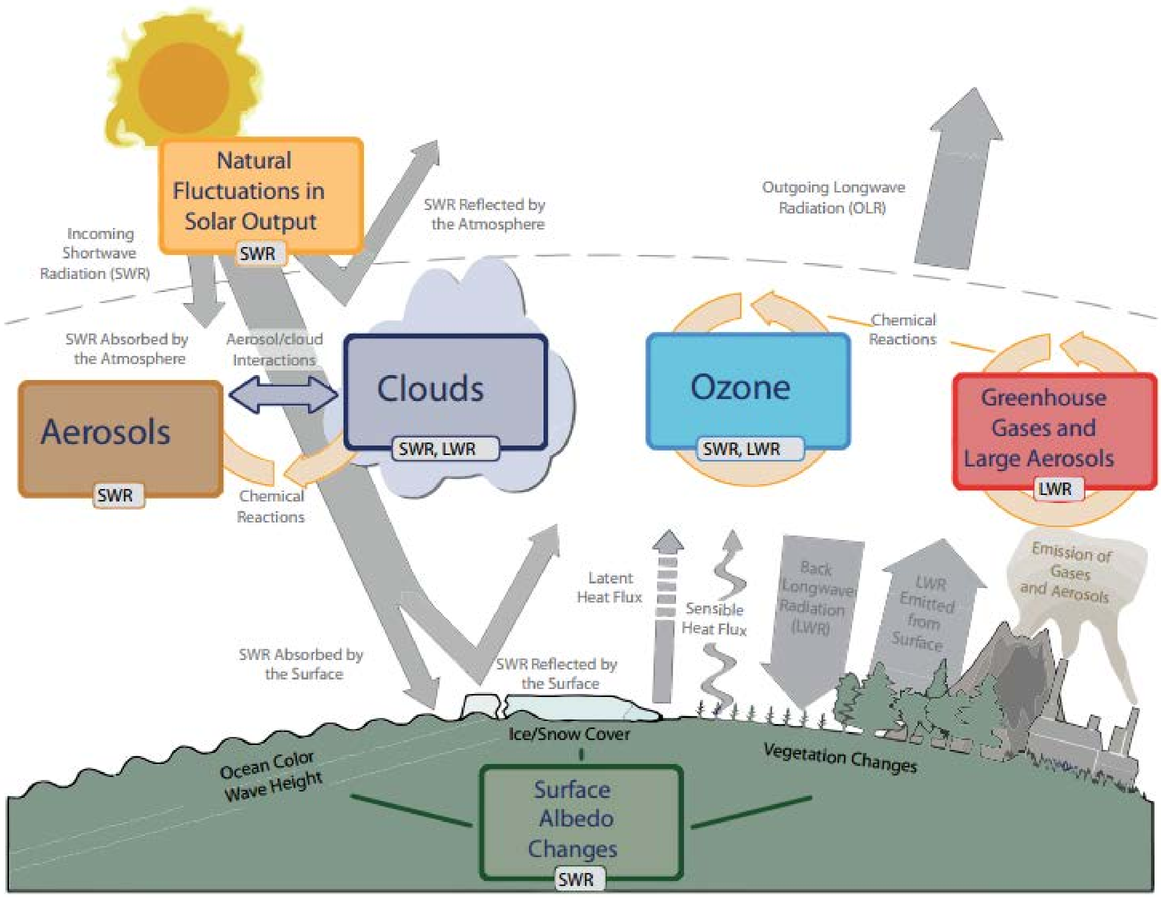
The observed changes in the global climate described in Section 5.2 are largely a result of GHG emissions from human activities. The IPCC has concluded that "[H]uman influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea-level rise, and in changes in some climate extremes. This evidence for human influence has grown since the IPCC *Fourth Assessment Report* (AR4). It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC 2013a).

Though the climate system is complex, scientists have identified main drivers that lead to changes in climate (*see* Figure 5.1.2-3). These drivers include the following:

- **GHGs**: Gaseous constituents found within the atmosphere, both natural and anthropogenic, that absorb and re-emit terrestrial infrared radiation. Primary GHGs found in the atmosphere are water vapor, CO_2, nitrous oxide (N_2O), methane (CH_4), and ozone (IPCC 2013a).
- **Aerosols**: Natural and manmade particles in Earth's atmosphere scatter incoming sunlight back to space, causing cooling. Some species are hygroscopic (i.e., attract water) and can affect the formation and lifetime of clouds. Large aerosols (more than 2.5 micrometers [µm] in size) modify the amount of outgoing long-wave radiation (IPCC 2013a). Other particles, such as black carbon, can absorb outgoing terrestrial radiation, causing a warming.
- **Clouds**: Depending on cloud height, cloud interactions with terrestrial and solar radiation can vary. Further, small changes in the properties of clouds can have important implications for both the transfer of radiative energy and weather (IPCC 2013a).
- **Ozone**: A GHG created through photochemical reactions from natural and manmade gases. Ozone in the troposphere is a GHG that absorbs and reemits long-wave radiation. Ozone in the stratosphere, known as the ozone layer, absorbs incoming short-wave radiation (IPCC 2013a).
- **Solar Radiation**: The amount of solar energy that reaches the top of Earth's atmosphere varies over time (IPCC 2013a).
- **Surface Changes**: Changes in vegetation or land surface properties, ice or snow cover, and ocean color can affect surface albedo (i.e., the fraction of solar radiation that will be reflected by a surface or object). The changes are driven by natural seasonal and diurnal changes (e.g., snow cover) as well as human influences (e.g., changes in vegetation type) (IPCC 2013a).

Most GHGs, including CO_2, CH_4, N_2O, water vapor, and ozone, occur naturally. Human activities such as the combustion of fossil fuel for transportation and electric power can contribute to very substantial increases in the concentrations of these gases in the atmosphere. In addition, a few very potent anthropogenic GHGs, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3), are almost entirely anthropogenic in origin. These gases are produced mainly for use in industrial processes (e.g., PFCs from aluminum production) and emitted to the atmosphere (e.g., as a result of leaks in refrigeration and air-conditioning systems).

Figure 5.1.2-3. Main Drivers of Climate Change



Source: IPCC 2013b.

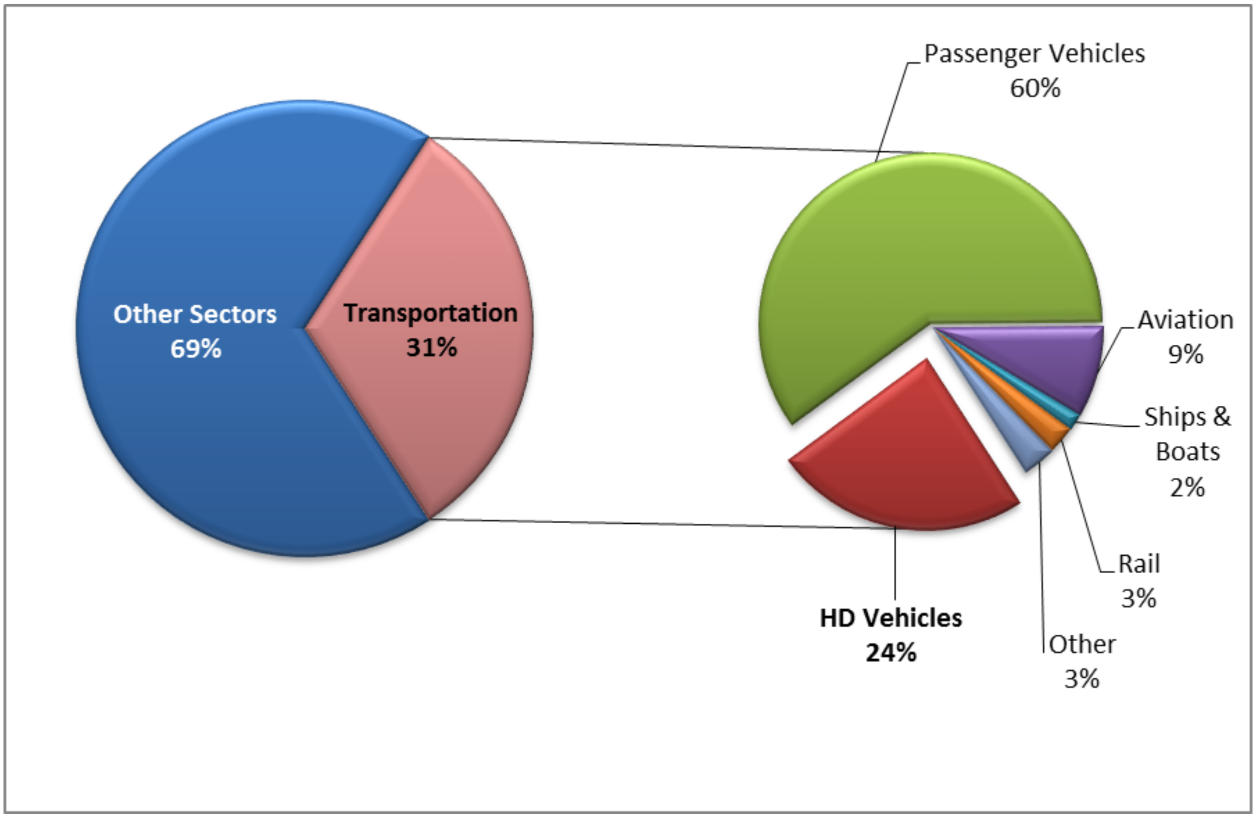
5.1.3 Anthropogenic Sources of Greenhouse Gases

Human activities that emit GHGs to the atmosphere include fossil fuel production and combustion; industrial processes and product use; agriculture, forestry, and other land uses; and waste management. Emissions of CO_2, CH_4, and N_2O from human activities comprise approximately 98 percent of annual anthropogenic GHG emissions addressed by national inventory reports (WRI 2016).[1] The global atmospheric CO_2 concentration has increased by 44 percent, from approximately 278 parts per million (ppm) in 1750 (IPCC 2013b) to approximately 399 ppm in 2015 (NOAA 2016). Atmospheric concentrations of CH_4 and N_2O have, by 2011, increased approximately 150 and 20 percent, respectively, since the beginning of the Industrial Revolution in the mid-1700s (IPCC 2013a). Isotopic- and inventory-based studies make clear that this rise in the CO_2 concentration is largely a result of the release of carbon that has been 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.

[1] 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 the World Resources Institute Climate Analysis Indicators Tool (CAIT), emissions from the United States account for approximately 15.1 percent of total global CO_2 emissions (WRI 2016).[2] EPA's National Greenhouse Gas Inventory for 1990 to 2014 indicates that in 2014, the U.S. transportation sector contributed about 31.3 percent of total U.S. CO_2 emissions, with HD vehicles accounting for 24.2 percent of total U.S. CO_2 emissions from transportation (EPA 2016c). Therefore, approximately 7.6 percent of total U.S. CO_2 emissions are from HD vehicles, and these vehicles in the United States account for 1.1 percent of total global CO_2 emissions (based on comprehensive global CO_2 emissions data available for 2012).[3] Figure 5.1.3-1 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 5.1.3-1. Contribution of Transportation to U.S. CO_2 Emissions and Proportion Attributable by Mode, 2014



Source: EPA 2016c.

5.1.4 Evidence of Climate Change

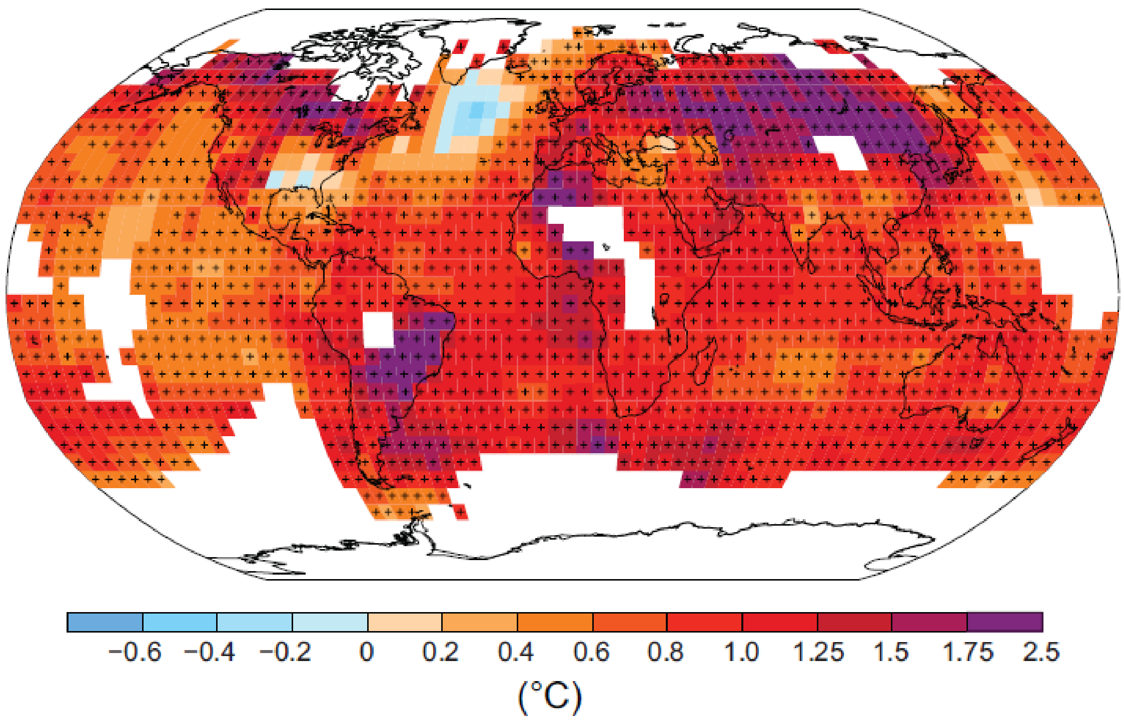
Observations and studies reporting trends from around the world demonstrate that Earth is undergoing climatic change much more quickly than would be expected from natural variations. As stated in the

[2] The estimate for global emissions from WRI is for 2012, the most recent year with available data for all GHGs. It excludes emissions and sinks from land use change and forestry.

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

Third National Climate Assessment (GRCP 2014), "Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans…Taken together, this evidence tells an unambiguous story: the planet is warming, and over the last half century, this warming has been driven primarily by human activity." The global average surface temperature is rising, with many regions across the globe experiencing more than a 0.4°C (0.7°F) warming since 1901 (IPCC 2013a). The last decade has been the warmest on record, and 2012 was the hottest year on record in the continental United States (GCRP 2014) (*see* Figure 5.1.4-1, below).

Figure 5.1.4-1. Observed Surface Temperature Change from 1901 to 2012[a]



[a] Derived from temperature trends determined by linear regression (IPCC 2013a).

A number of trends observed over the 20th century further support the evidence of climate-induced changes, for example:

- Most land areas have *very likely* experienced warmer and/or fewer cold days and nights along with warmer and/or more frequent hot days and nights (IPCC 2014a).
- Cold-dependent habitats are shifting to higher altitudes and latitudes, and growing seasons are becoming longer (GCRP 2014, IPCC 2014a).
- Sea level is rising, caused by thermal expansion of the ocean and melting of snow and ice (IPCC 2013a).
- More frequent weather extremes such as droughts, floods, severe storms, and heat waves have been observed (GCRP 2014, IPCC 2013a).
- Oceans are becoming more acidic as a result of increasing absorption of CO_2 by seawater, which is driven by a higher atmospheric concentration of CO_2 (GCRP 2014, IPCC 2013a, UN 2016). Recent evidence suggests with *high confidence* that oceans have become about 26 percent more acidic since the Industrial Revolution (IPCC 2013a, UN 2016).

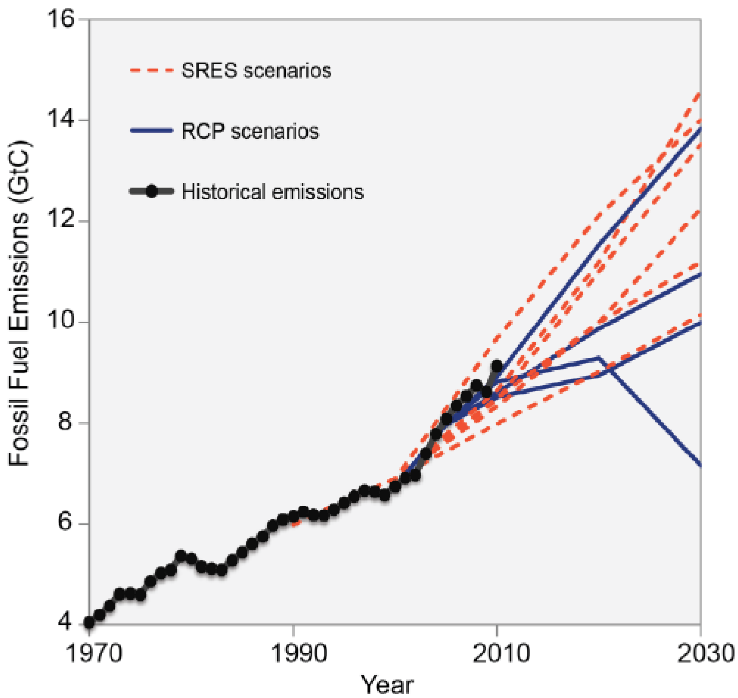
The weight of evidence that climate change is already occurring supports the projections of incremental environmental changes in the future. As discussed later in this chapter, although NHTSA has quantified the impacts of the alternatives on several climate parameters, it is very difficult to translate these changes to damages on specific resources quantitatively. Nonetheless, it is clear from current trends that these resources are likely to be affected to some degree by climate change.

This section provides a qualitative analysis of these trends, which is useful for the decisionmaker in consideration of the projected impacts of the Final Action and alternatives. As discussed below, each of the action alternatives would, to a greater or lesser extent, result in decreased GHG emissions compared with the No Action Alternative. The more the alternatives would reduce GHG emissions, the more they would be expected to also reduce the direct and indirect risks associated with these phenomena. Additional evidence of climate change is discussed throughout this section.

5.1.5 Future Climatic Trends and Expected Impacts

As the world population grows over the 21st 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 substantial 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 (IPCC 2013b). The effects of the CO_2 emissions that have accumulated in the atmosphere prior to 2100 will persist well beyond 2100. If current trends continue, this elevation in atmospheric CO_2 concentrations will persist for many centuries, with the potential for temperature anomalies continuing much longer (IPCC 2013b). In addition, global GHG emissions since 2000 have been increasing at a growth rate nearly three times greater than that of the 1990s (IPCC 2013b). Comparing observed carbon emissions to projected emissions, the current trajectory is similar to the most fossil fuel-intensive emissions scenario (A1Fi) in the *IPCC Special Report on Emissions Scenarios* (SRES) (2000) and the highest (RCP8.5) emissions scenario represented by the more recent Representative Concentration Pathways (RCP) (IPCC 2013b) (*see* Figure 5.1.5-1).

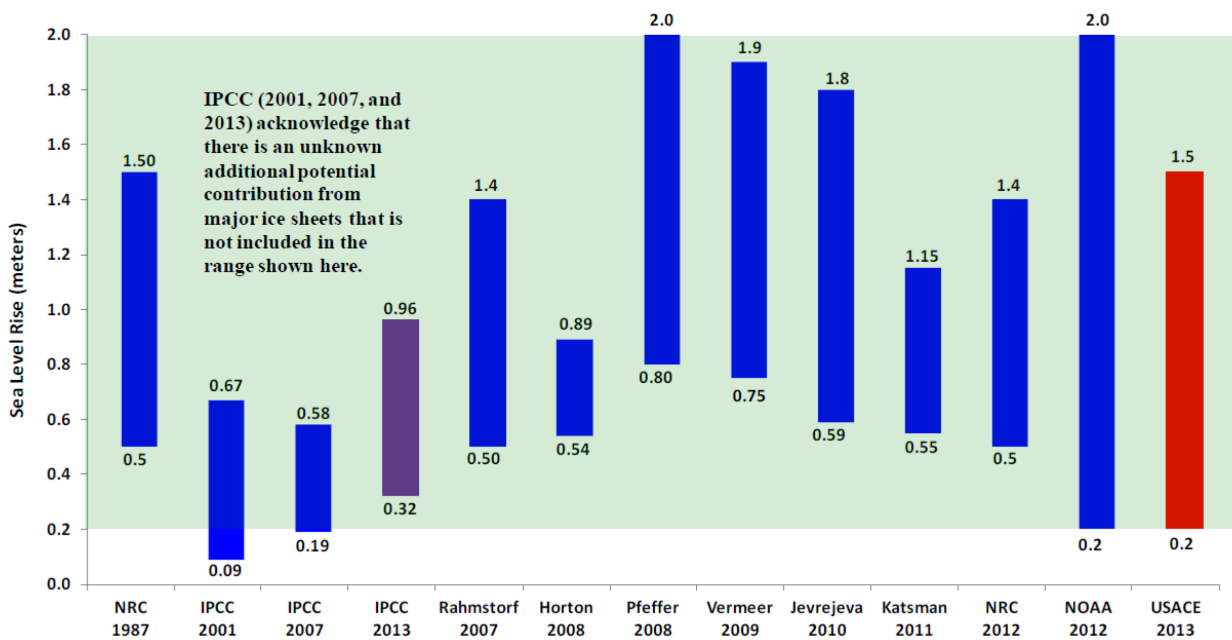
Figure 5.1.5-1. Historical and Projected Carbon Emissions



Source: IPCC 2013b. Notes: SRES = Special Report on Emissions Scenarios; RCP = Representative Concentration Pathways; GtC = gigatonnes of carbon.

Between 2081 and 2100, the IPCC projects an average increase in surface temperature, with a *likely* range between 0.3°C (0.5°F) and 4.8°C (8.6°F), compared with 1986 through 2005, where the lower value corresponds to substantial future mitigation of carbon emissions (IPCC 2013b). At the national, regional, and local levels, there can be substantial differences in warming compared with the global average. These differences are due to the influence of smaller scale factors, such as topography and changes in land use, on local-scale climates (GCRP 2014). Elevated global average temperatures are anticipated to persist even if atmospheric CO_2 concentrations decline. Because of the large heat capacity of the oceans, it may be centuries from now before all the warming from a given level of CO_2 concentrations are realized. Therefore, although 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 equilibrium with the atmosphere (Matthews and Caldeira 2008, IPCC 2013b). In addition, the IPCC projects that this temperature increase will affect sea level, causing a *likely* rise of 0.26 meter (0.85 feet) to 0.82 meter (2.7 feet) (IPCC 2013b). Satellite observations suggest such changes are beginning. In addition to IPCC projections, which do not include potential sea-level rise that could occur from melting/calving of major ice sheets, other studies, including semi-empirical analysis, indicate that sea-level rise could be even greater (*see* Figure 5.1.5-2). There is "*very high confidence* (more than 9 in 10 chance) that global mean sea level will rise at least 0.2 meter (7.9 inches) and no more than 2.0 meters (6.6 feet) by 2100" (NOAA 2012b). Delaying reductions in anthropogenic GHG emissions will increase the concentration at which CO_2 stabilizes in the Earth's atmosphere, increasing the risk of greater warming and greater sea-level rise (IPCC 2014a).

Figure 5.1.5-2. End-of-Century (~2090–2100) Estimates of Maximum and Minimum Global Mean Sea-Level Rise



Source: USACE 2014.

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.

5.1.6 Black Carbon and Other Aerosols

Aerosols are solid or liquid particles suspended in Earth's atmosphere. The chemical composition of aerosols varies enormously and can include sulfates, nitrates, dust, black carbon, and other chemical species (IPCC 2013b, CCSP 2009). Aerosols are either emitted directly from a source (e.g., power plants, forest fires, and volcanoes) into Earth's atmosphere or chemically created in the atmosphere from gases (IPCC 2013b, CCSP 2009).

HD vehicles contribute to U.S. emissions of black carbon, but there is no evidence to suggest that the alternatives differ substantially in terms of their effect on black carbon and aerosol emissions. However, given their important influence on climate, this section provides an overview of these emissions and their climatic interactions.

Depending on meteorological conditions and other factors, aerosols typically remain in Earth's atmosphere from a few days to more than a week (IPCC 2013b). Their relatively short lifetimes can create regional areas of high aerosol concentrations nearby as well as some distance downwind from emissions source(s) (IPCC 2013b). Therefore, unlike GHGs, any climatic impact of aerosols could be evaluated at the regional scale.

An aerosol's effect on climate depends on its composition. Some aerosols, such as sulfates, reflect incoming sunlight back to space, causing a cooling effect; other aerosols, such as black carbon, absorb incoming sunlight, causing a warming effect (CCSP 2009, IPCC 2013b). In addition, some aerosols attract moisture/water vapor and can affect the lifetime and reflectivity of clouds. Overall, IPCC (2013b) believes that aerosols cool Earth's atmosphere from the reflection of incoming sunlight and their interaction with clouds, though large uncertainties exist (*see* Section 5.1.6.3). The overall effect of aerosols on precipitation is not known at the global scale, and this topic continues to be an active area of research (IPCC 2013b).

Among the aerosols, black carbon has recently attracted much attention because of its strong effect on 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).[4] Reports from the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) suggest that a reduction in black carbon emissions could reduce global mean warming rates over the next few decades, while reductions in 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; significant scientific uncertainties remain regarding black carbon's total climate effect.[5] The interaction of black carbon (and other co-emitted aerosols) with clouds is especially poorly quantified (IPCC 2013b), 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

[4] 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.

[5] 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 Fifth Assessment Report (2013).

carbon climate impacts in an analysis of the Final Action and alternatives. Therefore, a qualitative description of the climatic effects and general characteristics of black carbon follows in Sections 5.1.6.1 through 5.1.6.5.

5.1.6.1 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 diesel vehicles for transport. They also have less stringent air emissions control standards and technologies. The United States contributes approximately 8 percent of the world's black carbon emissions (EPA 2012d), making the United States the seventh largest emitter worldwide (Lamarque et al. 2010).[6] In 2005, the United States emitted approximately 0.64 million short tons (580 gigagrams) of black carbon (EPA 2012d). The transportation sector is the single largest contributor in the United States, accounting for approximately 52 percent of U.S. black carbon emissions, followed by wildfires and agriculture/prescribed burns (Battye et al. 2002, Bond et al. 2004, EPA 2012d).[7] Approximately 80 percent of mobile-source black carbon emissions in the United States are from on-road and non-road diesel sources, at 208,473 and 145,289 short tons, respectively, for 2005 (EPA 2012d). There is considerable uncertainty surrounding black carbon emissions estimates; Ramanathan and Carmichael (2008) estimate 50 percent uncertainty in global estimates, while the uncertainty in regional emissions estimates can range from a factor of 2 to 5.

The *IPCC WG3 AR5* (2014b) suggests there is strong evidence to support the reduction of black carbon emissions from HD vehicles as a means for providing a short-term mitigation strategy to curb future global warming. If overall fuel consumption continues to increase over time, this could lead to an increase in black carbon emissions. However, improvements in emissions technology and reductions in black carbon emissions could offset some of the future increase in fuel consumption (IPCC 2014b).

5.1.6.2 Climatic Interactions

Although black carbon has been an air pollutant of concern for years because of its direct human health effects, climate change experts have become concerned with it because of its influence on climate change (EPA 2009, 2012d). Recent studies suggest black carbon is a major contributor to anthropogenic warming because it affects regional net radiative forcing[8] 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[9] and enhancing melting; (3) as it warms the atmosphere, it triggers cloud evaporation; and (4) as

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[6] This is consistent with the findings provided in the IPCC Fifth Assessment Report (2013), which suggest that North America emits between 0.3 to 0.4 Teragrams per 2000 year of black carbon, which equates to approximately 6 to 8 percent of the total emissions worldwide.

[7] Bond et al. (2004) used 1996 fuel data and estimated global black carbon emissions (in PM2.5) to be 8,000 gigagrams. This sector alone is responsible for 36 percent of all black carbon emissions in the United States, similar to that for prescribed forest burning. 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 (PM2.5) emissions, which were then proportioned to black carbon for U.S. on-road diesel vehicles (65 to 89 gigagrams), non-road diesel vehicles (65 gigagrams), and on-road gasoline vehicles (16 to 35 gigagrams).

[8] Radiative forcing (RF) describes the magnitude of change in energy fluxes caused by a specific driver that can alter the Earth's energy budget. The IPCC (2013a) provides radiative forcing for 2011 relative to 1750. A positive RF leads to a warming while a negative RF leads to a cooling (IPCC 2013a).

[9] 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.

it ages in the atmosphere, it can become hygroscopic, reducing precipitation and increasing the lifetime of clouds (IPCC 2013b, EPA 2009, Ramanathan and Carmichael 2008, Kopp and Mauzerall 2010, EPA 2012d). 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. This causes 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 and reflective surface (such as snow or ice), which would normally reflect sunlight at a high rate, the particles have a lesser effect at Earth's surface. Regardless of the characteristics of the underlying surface, black carbon particles cause warming in the atmosphere above the Earth's surface.

When black carbon is deposited on snow and ice, it reduces the albedo because it absorbs incoming solar radiation and contributes to enhanced melting (EPA 2009, Ramanathan and Carmichael 2008, Flanner et al. 2007, EPA 2012d). 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). The Arctic has also experienced accelerated spring melting and a longer melt season in response to black carbon deposition (Quinn et al. 2008). In fact, 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). Another recent study modeled black carbon and dust deposition and found that they cause substantial warming over large areas of the Arctic Ocean and sub-Arctic seas during the fall and winter months (Goldenson et al. 2012). Impacts of black carbon on the Arctic vary with the origin of emissions. Emissions from within the Arctic (e.g., emissions from parts of Alaska, Canada, Greenland, Russia, and Norway) are more likely to stay close to Earth's surface and deposit on snow and ice, while emissions transported from the mid-latitudes are more likely to remain at high altitudes. It is suggested that emissions from within the Arctic affect surface temperatures five times more than emissions from mid-latitudes (Sand et al. 2013).

The complex interaction of black carbon with the radiative properties of clouds is an area under active research. Some aerosols suppress the formation of larger cloud droplets, which can extend the life of the cloud and increase cloud cover (IPCC 2013b, Ramanathan and Carmichael 2008). In addition, reducing precipitation can extend the atmospheric lives of aerosols. Although initially 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 process 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).

5.1.6.3 Net Radiative Effect

The *IPCC WG1 AR5* (2013b) suggests that the interaction of aerosols, including black carbon, with radiation and clouds leads to a cooling of -0.9 Watts per square meter (W/m^2), with *medium confidence* that the forcing is between -1.9 to -0.1 W/m^2 and a *likely* range of -1.5 to -0.4W/m^2.[10] From 1750 to 2010, the radiative forcing of black carbon emissions from fossil fuel and biofuel is estimated to have been a warming of 0.4 W/m^2, with a 5 to 95 percent uncertainty range of 0.05 to 0.8 W/m^2 (IPCC 2013b).[11] These estimates do not account for the effect on other aspects that affect the radiative budget, such as interactions with cloud properties and changes in snow and sea ice. Of these additional effects, the radiative forcing associated with the deposition of black carbon on snow and sea ice is estimated to be 0.04 W/$m^{2,}$ with an uncertainty range of 0.02 to 0.09 W/m^2 (IPCC 2013b).

The ranges presented are, in part, due to the different treatment of black carbon across global-scale modeling studies and the variation in regional concentrations, which hinders attempts to obtain a consistent estimate of its radiative effects. For example, modeling studies vary in how several key factors are weighted, including emissions 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). In addition, Spracklen et al. (2011) suggests black carbon acting to promote the development of cloud droplets plays a substantial role in increasing the radiative cooling caused by clouds, emphasizing the importance of including this mechanism when considering the particle’s net effect on climate.

5.1.6.4 Comparison to Properties of Greenhouse Gases

Black carbon has a much shorter atmospheric lifespan than GHGs. The *IPCC WG1 AR5* (2013b) estimates the life of black carbon in the atmosphere as being approximately 7 to 10 days, generally depending on meteorological conditions. This lifetime is quite short compared with the atmospheric life of CO_2 in the atmosphere.[12] This short life suggests black carbon’s effects are greatest near the emissions 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.

As with the warming associated with GHGs, the physical environment reacts to the climatic impacts of black carbon. For example, black carbon can contribute to the warming of permafrost in the Arctic region. As permafrost warms, it releases large amounts of methane into the atmosphere, leading to additional warming (EPA 2009). As another example, the warming associated with black carbon can contribute to earlier melting of sea ice in the Arctic, exposing open oceans earlier in the year. The open oceans absorb solar radiation that would have been reflected by sea ice, leading to enhanced regional warming (EPA 2009). *See* Section 5.5.2 for an additional discussion of these and other interactions.

5.1.6.5 Controls and Regulatory Options that Affect Black Carbon Emissions from Diesel Trucks

Based on estimates of U.S. on-road and non-road diesel emissions of black carbon in fine particles (PM2.5) (Battye et al. 2002) and global emissions of black carbon in PM2.5 (Bond et al. 2004), HD vehicles in the United States contribute slightly more than 3 percent of global black carbon emissions. Historically, diesel vehicles have emitted more black carbon than gasoline vehicles on a per-mile basis.

[10] These estimates are based on global climate model results, satellite estimates, and expert judgment.

[11] IPCC (2013b) used expert judgment and was informed by the findings of Bond et al. (2013) and Myhre et al. (2013).

[12] The removal of human-emitted CO_2 from the atmosphere by natural processes will take a few hundred thousand years (high confidence) (IPCC 2013b).

Improved fuel efficiency associated with this rulemaking will reduce black carbon emissions, as diesel fuel use will decrease compared to the No Action Alternative. Separately, and more importantly, widespread deployment of recent, more effective control technologies for particulate matter emissions from diesel vehicles and the use of low-sulfur diesel fuel would most likely reduce emissions of black carbon.

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 impacting climate in detectable and quantifiable ways.

This section includes a discussion of GHG emissions (Section 5.2.1) and climate change effects (Section 5.2.2). 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 descriptions of conditions globally and in the United States. Many themes in the discussions regarding conditions in the United States reappear in the global discussions.

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, to power trains and cars, and to run factories and industrial operations. Today, fossil fuels are still the primary source of energy and predominant source of GHG emissions around the world.

As noted earlier, the concentration of atmospheric CO_2 has been rising rapidly. The atmospheric CO_2 level was estimated to be 278 ppm in 1750 and has since been rising steadily (IPCC 2014b citing Etheridge et al. 1996, Etheridge et al. 2002; NRC 2011b; and IPCC 2013a). Since the Industrial Revolution, atmospheric CO_2 concentration has risen by about 44 percent to approximately 399 ppm in 2015 (NOAA 2016). In addition, the concentrations of CH_4 and N_2O in the atmosphere increased about 150 and 20 percent, respectively, by 2011 (IPCC 2013a).

In 2012, global GHG emissions were estimated to be 47,599 million metric tons of CO_2e ($MMTCO_2e$), a 40.3 percent increase since 1990 (WRI 2016).[13] 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 hydrofluorocarbons (HFCs), perfluorocompounds (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). In 2012, CO_2

[13] Unless otherwise stated, all GHG estimates cited in Section 5.2.1.1 include contributions from land-use change and forestry and international bunker fuels. The most recent emissions estimates for all gases from WRI CAIT are for 2012.

emissions[14] comprised 76 percent of global GHG emissions on a global warming potential (GWP)-weighted basis, followed by CH_4 (16 percent) and N_2O (7 percent). Collectively, fluorinated gases represented 2 percent of global emissions covered by national inventories (WRI 2016).

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 72 percent of global emissions in 2012. The next-highest contributors of GHG emissions are agriculture (11 percent) and industrial processes (6 percent) (WRI 2016). Transportation CO_2 emissions comprise roughly 15 percent of total global GHG emissions (included in the 72 percent cited above for the energy sector [WRI 2016]). Emissions from transportation are primarily due to the combustion of petroleum-based fuels to power vehicles. Global transportation CO_2 emissions have increased by 57 percent from 1990 to 2012 (WRI 2016).

5.2.1.2 U.S. Emissions

GHG emissions for the United States in 2014[15] were estimated at 6,870.5 $MMTCO_2e$ (EPA 2016c). U.S. emissions comprise approximately 14 percent of global GHG emissions (WRI 2016).[16] Annual net U.S. emissions, which have increased 8 percent since 1990, are heavily influenced by "general economic conditions, energy prices, weather, and the availability of non-fossil alternatives" (EPA 2016c).

Similar to the global trend, CO_2 is by far the primary GHG emitted in the United States, representing 80.9 percent of U.S. GHG emissions in 2014 (EPA 2016c). Methane accounts for 10.6 percent of total GHGs on a GWP-weighted basis, followed by N_2O (5.9 percent) and the fluorinated GHGs or gases (2.6 percent) (EPA 2016c).[17]

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 76 percent of total U.S. emissions (EPA 2016c). The CO_2 emissions due to combustion of fossil fuels are from fuels consumed in the electric power (39 percent of fossil fuel emissions), transportation (33 percent), industry (16 percent), residential (7 percent), and commercial (4 percent) sectors, with the remaining emissions, from U.S. territories, accounting for less than 1 percent of the total (EPA 2016c). When U.S. CO_2 emissions are apportioned by end use, transportation is the single leading source of U.S. emissions from fossil fuels, causing almost one-third of total CO_2 emissions from fossil fuels (EPA 2016c).[18]

CO_2 emissions from HD vehicles account for almost a quarter of U.S. transportation CO_2 emissions, and have increased by 77 percent since 1990 (EPA 2016c). This increase was primarily driven by both cost competitiveness due to low fuel prices and use of a manufacturing industry inventory system called Just in Time, which is a manufacturing production system that reduces inventory and associated carrying costs. Low fuel prices during the 1900s and much of the 2000s made trucks a more attractive mode of transportation, and, in conjunction with the rise in businesses using the Just in Time inventory

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[14] These global GHG estimates *do not* include contributions from land-use change and forestry or international bunker fuels.

[15] Most recent year for which an official EPA estimate is available (EPA 2016c).

[16] Based on global and U.S. estimates for 2012, the most recent year for which a global estimate is available. Excluding emissions and sinks from land use change and forestry and international bunker fuels.

[17] Fluorinated GHGs or gases include PFCs, HFCs, SF_6, and NF_3.

[18] Apportioning by end use allocates emissions associated with electricity generation to the sectors (residential, commercial, industrial, and transportation) where it is used.

management to transport goods in a way that is more quick and timely, these trends contributed to the increased market share for trucks (C2ES 2014b). From 1970 to 2003, energy consumption increased more rapidly in the HD vehicle sector than in the light-duty vehicle sector (C2ES 2014c).

5.2.2 Climate Change Effects—Historic and Current

In its most recent assessment of climate change (the Fifth Assessment Report [AR5]), the IPCC states that, "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC 2013a). The IPCC concludes that, at continental and global scales, numerous long-term changes in climate have been observed. These include changes in polar (Arctic and Antarctic) temperatures and ice cover, widespread changes in precipitation amounts, ocean salinity, and extreme weather including droughts, heat waves, and precipitation intensity (IPCC 2013b).

This section provides an overview of observed historical and current climate change and ocean salinity 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: AR5 Working Group II (Impacts, Adaptation, and Vulnerability) Summary for Policymakers (IPCC 2014a), Third National Climate Assessment (GCRP 2014), and Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act (EPA 2009). The impacts associated with these observed trends are further discussed in Section 5.5.

Sections 5.2.2.1 through 5.2.2.3 address increased temperatures, sea-level rise, and changes in precipitation patterns, respectively. Section 5.4 of this EIS provides a quantitative analysis of the effects of the regulatory alternatives on each of these three climate attributes.

Sections 5.2.2.4 through 5.2.2.6 address increased incidence of severe weather, changes in ice cover and extent, and ocean acidification. They are described to provide a more complete discussion of historic and current climate change trends and impacts. As discussed below, although the incremental effects of the alternatives are not quantified for these impacts, the more the alternatives reduce GHG emissions, the more they reduce the direct and indirect risks associated with these phenomena.

5.2.2.1 Increased Temperatures

5.2.2.1.1 Radiative Forcing

Global average surface temperature has been increasing over the past century in response to anthropogenic GHG emissions. As noted in Section 5.1, radiative forcing (RF) describes the magnitude of change in energy fluxes caused by a specific driver—in this case, anthropogenic GHGs—that can alter the Earth's energy budget. A positive RF leads to a warming while a negative RF leads to a cooling (IPCC 2013a). GHGs have a positive RF. The IPCC states that scientific evidence shows that the total anthropogenic RF has increased by 2.29 watts per square meter (Wm^{-2}) (plus 1.04 or minus 1.16 Wm^{-2}) and is responsible for the observed warming. The RF from increased atmospheric CO_2 concentration alone is estimated to be 1.68 Wm^{-2} (plus 0.35 or minus 0.35 Wm^{-2}) (IPCC 2013a). The IPCC also indicates that previous estimates of total anthropogenic RF had, in fact, underestimated recent changes in RF: "The total anthropogenic RF best estimate for 2011 is 43 percent higher than that reported in AR4 for the year 2005" (IPCC 2013a).

5.2.2.1.2 Average Temperatures

In the years from 1880 to 2012, the global mean surface temperature has risen by 0.8 plus or minus about 0.2°C (1.4 plus or minus about 0.4°F) (IPCC 2013a). Temperatures are rising at an increasing rate. The average rate of increase since 1951 was 0.12 plus or minus 0.03°C (0.22 plus or minus 0.05°F) per decade. The average Arctic temperature has increased at almost twice the global average rate over at least the past several decades (GCRP 2014). Air temperatures over land are warming more rapidly than those over oceans (GCRP 2014, IPCC 2013a).

Throughout the 2000s, the contiguous United States and Alaska experienced a lack of cold waves, compared with historical averages (GCRP 2014). Similar to the global trend, the U.S. average temperature is now 1.30–1.90°F warmer than it was in 1895, and this rate of warming is increasing—most of the warming has occurred since 1970 (GCRP 2014). Global ocean temperatures have also continued to warm. The upper 75 meters (246 feet) of the global ocean has warmed by 0.11 plus or minus 0.02°C (0.20 plus or minus 0.4°F) per decade between 1971 and 2010 (IPCC 2013a). Surface temperatures are not rising uniformly around the globe. For example, some areas of the southeastern, Midwestern, and Great Plains regions of the United States have experienced “warming holes” because recent temperature observations during the 20th century suggest only minor to no warming trends in those areas (GCRP 2014).

5.2.2.1.3 Extreme Temperatures

Across regions of the world including the United States, extreme temperatures have changed substantially since about 1950. Hot days, hot nights, and heat waves have become more frequent; cold days, cold nights, and frost have become less frequent (EPA 2009, GCRP 2014, IPCC 2013b). 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; one notable exception is that the drought that has been occurring in the western states for the last decade is the most severe on record (GCRP 2014). Additionally, fewer unusually cold days occurred in the past few decades, with fewer severe cold waves than historically indicated. The number of extreme cold events in the 2000s–2010s, thus far, has been at the lowest level dating back to at least 1895 (the inception of detailed record-keeping) (GCRP 2014). It is now considered *very likely* that humans have contributed to extreme heat events since the middle of the 20th century and is also *likely* that human activities have doubled the probability of extreme heat events in some regions (IPCC 2013b).

Weather balloons (which have been used since around the turn of the 20th century and were in routine use by 1958) and satellites (which have been used since the 1970s) have recorded increases in temperatures since their inception (GCRP 2014). 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 20th century (IPCC 2014a, GCRP 2014), and plant flowering and animal spring migrations are occurring earlier (EPA 2009, IPCC 2014a, GCRP 2014). Permafrost top layer temperatures have generally increased since the 1980s (approximately 3°C [5°F] in parts of Alaska and 2°C [4°F] in northern Russia), while the depths of seasonally frozen ground has, in some parts of the Eurasian continent, decreased since 1930 by approximately 0.3 meter (1 foot) (IPCC 2013b). The 4 to 5°F warming in Alaska permafrost has been recorded at a depth of 65 feet (GCRP 2014 citing NRC 2011 and Hawkins and Sutton 2009); at a depth of about 3 feet, the warming has been recorded as 6 to 8°F (GCRP 2014 citing Hansen and Sato 2012).

5.2.2.2 Sea-Level Rise

5.2.2.2.1 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. Since the early 1970s, glacier loss and thermal expansion, together, contributed approximately 75 percent to observed sea-level rise. It is *very likely* that human contributions to sea-level rise are substantial (IPCC 2013b).

Between 1971 and 2010, global ocean temperature warmed by approximately 0.25°C (0.45°F) in the top 200 meters (0.12 mile) (IPCC 2013b). In the top 700 meters (0.43 mile) of the ocean column, warming contributed an average of 0.6 plus or minus 0.2 millimeter (0.024 plus or minus 0.0079 inch) per year to sea-level rise (IPCC 2013b), 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 2010, and satellite observations indicate that they have contributed to sea-level rise in the years since (IPCC 2013b). 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 (up to 74 percent) of the Antarctic net mass loss and about half of the Greenland net mass loss (IPCC 2013b).

5.2.2.2.2 Observed Global Sea-Level Rise

It is *very likely* that global average sea level rose at an average rate of 1.7 plus or minus 0.3 millimeters (0.07 plus or minus 0.011 inch) per year from 1901 to 2010, with the rate increasing to approximately 3.2 plus or minus 0.4 millimeters (0.13 plus or minus 0.016 inch) per year from 1993 to 2010 (IPCC 2013a). Global mean sea level rose about 19 centimeters (7.5 inches) from 1901 to 2010 (IPCC 2013a).

5.2.2.2.3 Observed Regional Sea-Level Rise

Sea-level rise is not uniform across the globe, primarily due to changes in the elevation of the land surface. 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 (IPCC 2013b citing Beckley et al. 2010).

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 (EPA 2009, National Science and Technology Council 2008).

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 horizontally by an average of 2.6 to 3.1 meters (8.5 to 10.2 feet) per year. In Louisiana, a full 90 percent of the shoreline has been eroding at an average horizontal rate of more than 12.0 meters (39 feet) per year (EPA 2009 and Nicholls et al. 2007).[19]

[19] The shoreline erosion in Louisiana is also affected by human alterations and loss of sediment supply (EPA 2009).

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 2014). Depending on atmospheric conditions, this evaporation 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 1970s over land and the oceans, and in the upper troposphere, largely consistent with air temperature increases (IPCC 2013b). 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 (IPCC 2013a).

5.2.2.3.1 Global, Regional, and National Precipitation Trends

Long-term trends in global precipitation amounts have been observed since 1901. Between 1901 and 2010, increases in precipitation have been observed in the mid- and higher-latitudes of both the northern and southern hemispheres, specifically in northwestern and eastern parts of North America, parts of Europe and Russia, and southern South America. Drying has been observed in the Sahel region of Africa, the Mediterranean, southern Australia, and parts of southeastern Asia. Spatial and temporal variability for precipitation is high, and data are limited for some regions (IPCC 2013b).

Over the contiguous United States, total annual precipitation increased approximately 5 percent from 1901 to 2014, on average. The greatest increases since 1991 (relative to 1901 to 1960) were noted in the Midwest (9 percent), the Northeast (8 percent), and the southern Great Plains (8 percent), and there were notable decreases in Hawaii and areas of the Southwest (GCRP 2014). Heavy precipitation events also increased, primarily during the last 3 to 5 decades, equating to more than 30 percent above the 1901 to 1960 average. This trend has been observed mainly in the Northeast (71 percent) and Midwest (37 percent) regions (GCRP 2014).

5.2.2.3.2 Global, Regional, and National Trends in Droughts

Observations of increased dryness since the 1950s suggest that some regions of the world have experienced longer, more intense droughts caused by higher temperatures and decreased precipitation, particularly in the tropics and subtropics (IPCC 2013b). Spatial variability for dryness is high and data availability is limited in some regions to draw global conclusions. While there is *likely* increased dryness or drought in East Asia, the Mediterranean, and West Africa, there has *likely* been decreased dryness observed in central North America and northwest Australia (IPCC 2013b).

Trends in droughts have been changing for some regions of the United States over the past 50 years (GCRP 2014). Most regions in the United States experienced decreases in drought severity and duration over the 20th century due to increasing average precipitation and the frequency of heavy precipitation events; although there are exceptions to this trend, such as the severe drought in the Southwest from 1999 to 2008 (EPA 2009), recent severe droughts in Texas in 2011 (GCRP 2014), the Midwest in 2012 (GCRP 2014) and California in 2014 continuing into 2015 (USGS 2015). According to tree ring data, drought conditions in the western United States over the last decade may represent the driest conditions in 800 years (GCRP 2014).

5.2.2.3.3 Global, Regional, and National Streamflow Trends

Melting snow and ice, increased evaporation, and changes in precipitation patterns all affect surface water. Previous assessments have indicated variable changes in streamflow and river discharge, with most increases observed at higher latitudes. Mean annual streamflow decreased approximately 2 percent per decade over the past century in the central Rocky Mountain region (IPCC 2007 citing Rood et al. 2005), while high streamflow increased 25 percent in the past 60 years in the eastern United States (IPCC 2013b citing Groisman et al. 2004). More recent assessments show even greater global variability in trends, where decreases in streamflow were observed in mainly low and mid-latitude river basins, while increasing flow at higher latitudes may be resulting from possible permafrost thawing and increased snowmelt (IPCC 2013b). Changes in precipitation have also been identified as a major driver for changing discharge trends across regions (IPCC 2013b).

5.2.2.3.4 Global, Regional, and National Trends in Snow Cover

Across the northern hemisphere, annual mean snow cover extent has decreased 53 percent over the period 1967 to 2012 (IPCC 2013b). Recent analysis of Arctic snowpack indicates that changes in air temperature, decreased surface albedo, and increased atmospheric water vapor have driven trends in snow cover recession observed between 1972 and 2006 (GCRP 2014 citing Shi et al. 2013). Between 2008 and 2012, Eurasia set five records for minimum snow extent during late spring, and North America set records in 3 years in the same period (GCRP 2014 citing Derksen and Brown 2012). In addition, North America, Europe, and southern and east Asia have experienced a decreasing number of snowfall events, *likely* due to increasing winter temperatures (IPCC 2013b).

5.2.2.4 Increased Incidence of Severe Weather Events

Analysis continues to support conclusions that heavy precipitation events have increased globally since 1951, with some regional and sub-regional variability (IPCC 2013b). Tropical cyclones appear to be increasing in intensity since 1970, but no clear trend in the frequency of tropical cyclones each year has been observed. Developing long-term trends of tropical cyclones continues to be problematic, because it has been difficult to draw *high confidence* conclusions with respect to observations prior to the satellite era (IPCC 2013b). However, there is observational evidence of an increase in intense tropical cyclone activity correlated with increases of tropical sea-surface temperatures in the North Atlantic, which includes the Atlantic Multidecadal Oscillation, since about 1970 (GCRP 2014). The frequency, intensity, and duration of hurricanes in the North Atlantic, including Category 4 and 5 hurricanes, have increased substantially since the early 1980s (GCRP 2014).

While recent assessments indicate that it is *unlikely* that the annual frequency of tropical storms and hurricanes have increased over the past century in the North Atlantic, the increase in intensity since 1970s in that region is *virtually certain* (IPCC 2013b). Additionally, recent models project that climate change may increase the frequency of the most intense hurricanes by the end of the century, but it is still unclear how overall frequency of events might change (GCRP 2014).

Evidence is insufficient to determine whether there are trends in large-scale phenomena such as the Meridional Overturning Circulation,[20] or in small-scale phenomena such as tornadoes, hail, lightning, and dust storms (IPCC 2013b).

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 substantially 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 (IPCC 2013b, GCRP 2014); since 1979, the

[20] 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.

annual average Arctic sea-ice area has been declining at a rate of 3.5 to 4.1 percent per decade (IPCC 2013b). 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 (IPCC 2013b).[21] 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 2009, National Science and Technology Council 2008). Average winter sea-ice thickness in the Arctic Basin *likely* decreased by approximately 1.3 and 2.3 meters (4.27 to 7.55 feet) from 1980 to 2008 (IPCC 2013b). The multi-year ice extent (ice that lasts at least two summers) has declined from about 7.9 million square kilometers (3 million square miles) in 1980 to as low as 3.5 million kilometers (1.35 million square miles) in 2012 (IPCC 2013b). 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 2009, National Science and Technology Council 2008).

5.2.2.6 Acidification of Oceans

Increasing atmospheric CO_2 concentration has forced oceans to absorb more CO_2 in recent decades, 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 2013b). Because pH is measured on a logarithmic scale, this represents a 30 percent increase in the hydrogen ion concentration of seawater, a substantial 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 may interfere with the calcification of coral reefs and, therefore, inhibit the growth and survival of coral reef ecosystems (EPA 2009, GCRP 2014, IPCC 2013b).

5.3 Analysis Methods

The methods NHTSA used to characterize the effects of the alternatives on climate have three key elements:

- **Analyzing the effects of each alternative on GHG emissions:** Many analyses of policies and regulations express their goals, and measure their effectiveness, in terms of GHG emissions reductions.
- **Estimating the monetized damages associated with GHG emissions and reductions attributable to each alternative:** Economists have estimated the incremental effect of GHG emissions, and monetized those effects, to express the social cost of carbon (SC-CO_2), the social cost of methane (SC-CH_4), and the social cost of nitrous oxide (SC-N_2O) in terms of dollars per ton of each gas. By multiplying the emissions reductions of each gas by estimates of their social cost, NHTSA derived a monetized estimate of the benefits of emissions reductions.
- **Analyzing how GHG emissions and reductions under each alternative affect the climate system (climate effects):** Climate models characterize the relationship between GHG emissions and various climatic parameters in the atmosphere and ocean system, including temperature, precipitation, and

[21] Permafrost thawing releases CO_2 and CH_4 into the atmosphere (*see* Section 5.5.2.10.6).

sea level. NHTSA translated the changes in GHG emissions associated with each action alternative to changes in temperature, precipitation, and sea level in relation to the No Action Alternative.[22]

In this EIS, impacts on GHG emissions and the climate system are expressed in terms of emissions, CO_2 concentrations, temperature, precipitation, and sea level for each of the alternatives.

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 impacts involve considerable uncertainty.

Sources of uncertainty include the following, in addition to many other factors:

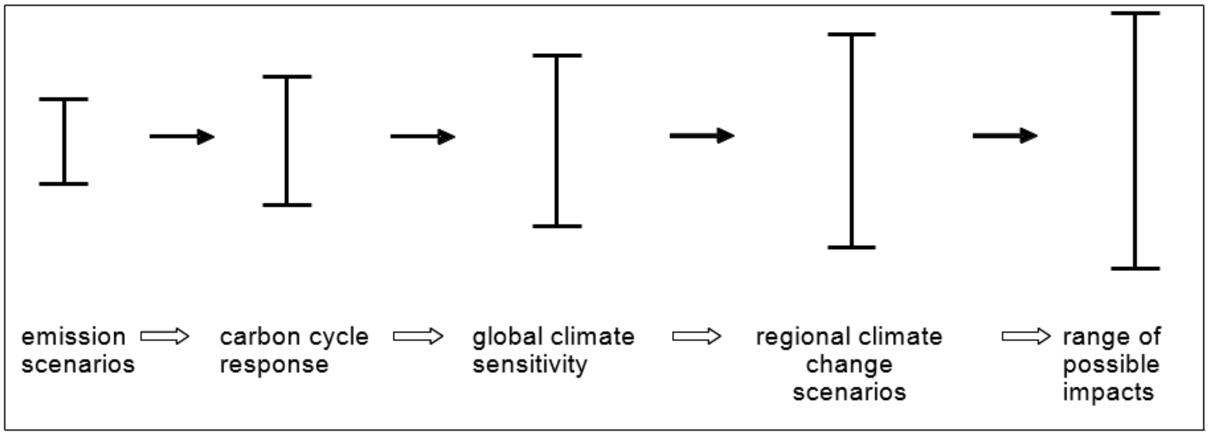
- The pace and effects of technology changes in the transportation sector and other sectors that emit GHGs.
- Changes in the future fuel supply and fuel characteristics that could affect emissions.
- Sensitivity of climate to increased GHG concentrations.
- The rate of change in the climate system in 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.

Moss and Schneider (2000) characterize the "cascade of uncertainty" in climate change simulations (Figure 5.3-1). As indicated in Figure 5.3-1, the emissions estimates used in this EIS have narrower bands of uncertainty than the global climate sensitivity, which is less uncertain than regional climate change impacts. The impacts 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.

[22] As explained in Chapter 2, the analysis of direct and indirect impacts compares action alternatives with the No Action Alternative, which reflects a small forecast increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond, due to market-based incentives for improving fuel efficiency. By including these market-based improvements in the No Action Alternative, this analysis attempts to isolate the portion of the fleet-wide fuel efficiency improvement attributable directly and indirectly to this rulemaking, and not attributable to reasonably foreseeable future actions by manufacturers.

Also as explained in Chapter 2, the cumulative impacts analysis compares the same action alternatives with the No Action Alternative, which assumes no increase in the average fuel efficiency of new HD vehicles MYs 2018 and beyond (i.e., no increase beyond the 2014–2018 Phase 1 HD standards). In other words, this baseline does not take into account market-based incentives for improving fuel efficiency. By comparing the action alternatives to this baseline, the cumulative impacts analysis reflects the combined impacts of market-based incentives for improving fuel efficiency after 2018 and the direct and indirect impacts of Phase 2 HD standards associated with each action alternative.

Figure 5.3-1. Cascade of Uncertainty in Climate Change Simulations



Source: Moss and Schneider 2000.

Scientific understanding of the climate system is incomplete; like any analysis of complex, long-term changes to support decisionmaking, evaluating reasonably foreseeable impacts on the human environment involves many assumptions and uncertainties. This EIS uses methods and data to analyze climate impacts that represent the best and most current 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 GCRP 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 the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) and the objECTS version of the Global Change Assessment Model (GCAM), are widely available and generally accepted in the scientific community.

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 2008a) provides a thorough discussion of the methodological limitations regarding modeling. Additionally, Chapter 9, Evaluation of Climate Models of *IPCC WG1 AR5* provides an evaluation of the performance of global climate models. Readers interested in a detailed treatment of this topic will find the SAP 3.1 report and Chapter 9 of *IPCC WG1 AR5* useful in understanding the issues that underpin the modeling of environmental impacts of the Final Action and the range of alternatives on climate change.

5.3.1 Methods for Modeling Greenhouse Gas Emissions

The emissions estimates in this EIS include GHG emissions resulting from HD vehicle fuel combustion (tailpipe emissions), as well as upstream emissions from the production and distribution of fuel. GHG emissions were estimated by EPA using two models:

- The Motor Vehicle Emissions Simulator (MOVES) model, described in Section 2.3.3, was used to calculate tailpipe emissions. In addition, for Classes 2b–3 vehicles, NHTSA used the Volpe model to calculate tailpipe emissions.
- An analysis using a spreadsheet model developed by EPA and based on emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (versions 1.8c and later developed by the U.S. Department of Energy [DOE] Argonne National Laboratory) was used to estimate emissions associated with production, transportation, and storage of gasoline and diesel from crude oil as well as emissions associated with the generation of electricity. The agencies

modified or updated some of the GREET values to be consistent with the EPA's National Emission Inventory (NEI) and emissions factors from 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 Phase 2 HD standards were estimated using the methods described in Section 2.3. For the climate analysis, GHG emissions trajectories are projected through year 2100. NHTSA estimated GHG emissions for the HD vehicle fleet for 2051 to 2100 by applying the projected rate of change in U.S. transportation fuel consumption over this period from GCAM. For 2051 through 2100, the GCAM Reference and GCAM 6.0 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 2050 does not change substantially. Therefore, emissions remain relatively constant from 2050 through 2100. The assumptions and methods used to develop the GHG emissions estimates for this EIS are broadly consistent with those used in the *MY 2012–2016 CAFE Final EIS* (NHTSA 2010b), *MY 2014–2018 Phase 1 HD Final EIS* (NHTSA 2011), and the *MY 2017–2025 CAFE Final EIS* (NHTSA 2012).

The emissions estimates include global CO_2, CH_4, and N_2O emissions resulting from direct fuel combustion and the production and distribution of fuel and electricity (upstream emissions). The MOVES model also estimated the following non-GHG emissions, which are used as inputs in MAGICC6: sulfur dioxide (SO_2), NO_x, CO, and volatile organic compounds (VOCs).

Fuel savings from more stringent HD vehicle fuel efficiency standards would result in lower emissions of CO_2, the main GHG emitted as a result of refining, distribution, and use of transportation fuels. 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. 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). NHTSA used two models to estimate fuel consumption and emissions impacts for various vehicle categories: (1) EPA's MOVES model for tractor-trailers and vocational vehicles, and (2) DOT's Volpe model for HD pickups and vans.

Reduced fuel consumption also lowers CO_2 emissions that result from the use of carbon-based energy sources during fuel production and distribution. EPA estimated the global reductions in CO_2 emissions during each phase of fuel and electricity production and distribution (i.e., upstream emissions) for various vehicle categories using (1) a combination of factors from DOE's GREET model and EPA analysis for upstream emissions impacts and EPA MOVES model emissions factors for tractor-trailers and vocational vehicles, and (2) DOT's Volpe model for HD pickups and vans. The upstream emissions were estimated using the CO_2 emissions rates obtained from the GREET model and EPA analysis using the previous assumptions about how fuel savings are reflected in reductions in activity during each phase of fuel production and distribution. 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. Emissions reductions continue well after the model years covered under the rule, as future new vehicles are assumed to meet or exceed the efficiency required under the final year of the rule.

5.3.2 Social Cost of Greenhouse Gas Emissions

This section describes the methods used to estimate the monetized damages associated with GHG 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 (SC-CO_2) that were revised in 2015 by the Interagency Working Group on Social Cost of Carbon (IWG), as well as estimates of the social costs of methane (SC-CH_4) and nitrous oxide (SC-N_2O) by Marten et al. (2014). This approach is consistent with the analysis of GHG impacts in the NHTSA and EPA joint Final Regulatory Impact Analysis (FRIA) for the Phase 2 HD Fuel Efficiency Improvement Program.

NHTSA has updated the methods for monetizing the social costs of CH_4 and N_2O reductions since publication of the Draft EIS. In the Draft EIS, NHTSA had monetized the benefits of CO_2 reductions in this SC-CO_2 analysis and conducted a sensitivity analysis using alternative estimates of the social benefits of reducing CH_4 and N_2O. The sensitivity analysis in the Draft EIS converted N_2O and CH_4 to CO_2 equivalent using GWPs from IPCC's Fourth Assessment Report's (AR4) and then applied the IWG SC-CO_2 values to the converted values. For this Final EIS, NHTSA assessed SC-CO_2 using the IWG's approach, and assessed SC-CH_4 and SC-N_2O using Marten et al.'s (2014) recommended approach, as described below. This approach is consistent with recent EPA RIAs, including those prepared for the *Proposed Emission Standards for New and Modified Sources in the Oil and Natural Gas Sector* and for the *Phase 2 HD Fuel Efficiency Improvement Program*, the former of which uses only the SC-CH_4 values, and the latter of which uses both the SC-CH_4 and SC-N_2O values. This approach is also consistent with the results of a 2015 EPA peer review of the application of the Marten et al. (2014) non-CO_2 social cost estimates in regulatory analysis.[23] The peer reviewers agreed that the SC-CH_4 estimates are generally consistent with the SC-CO_2 estimates, leading EPA to conclude that use of the SC-CH_4 estimates is an analytical improvement over excluding methane emissions from the monetized portion of the benefit-cost analysis. The reviewers also agreed that the method of converting non-CO_2 gases to CO_2-equivalents using GWPs and multiplying them by the SC-CO_2 has limitations, and that Marten et al.'s (2014) recommended approach yields a more accurate estimate of the social costs of non-CO_2 gases.

5.3.2.1 Social Cost of CO_2

The SC-CO_2 is used to estimate damages associated with an incremental increase in CO_2 emissions in a given year, on a monetized basis. To estimate the monetized benefits associated with CO_2 reductions under each action alternative, NHTSA multiplied the estimated value of the SC-CO_2 during each future year by the incremental emissions reductions estimated to result in a given year. NHTSA then discounted the sum of future benefits (at 5, 3, and 2.5 percent) to provide the net present value in 2015. The following description parallels the discussion about GHG benefits in the NHTSA and EPA joint FRIA and provides details of this analysis.

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[23] For a copy of the peer review responses, see Docket ID EPA-HQ-OAR-2010-0505-5016. Also available at <https://cfpub.epa.gov/si/si_public_pra_view.cfm?dirEntryID=291976> (see "SCCH4 EPA PEER REVIEW FILES.PDF").

The SC-CO_2 is a metric that includes a wide range of anticipated climate impacts, such as net changes in agricultural productivity and human health, property damage from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. It is typically used to assess the avoided damages as a result of regulatory actions (i.e., benefits of rulemakings that lead to an incremental reduction in cumulative global CO_2 emissions). The SC-CO_2 estimates were developed using four different discount rates for each year through 2050, to account for variations in how society may value anticipated future social impacts of climate change. The estimates used in this analysis are presented in the IWG's *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866* (May 2013, Revised July 2015), henceforth denoted as the current SC-CO_2 TSD (IWG 2015a). These estimates were first developed in 2010 through an interagency process that included DOT, EPA, and other Executive Branch entities.

The IWG selected four SC-CO_2 values for use in regulatory analyses; NHTSA has converted these values to 2013 dollars for this analysis.[24] Values for emissions occurring in the year 2015 are approximately \$12, \$39, \$61, and \$115 per metric ton of CO_2 ($MTCO_2$) (reported in 2013 dollars). The first three of these values are based on the average SC-CO_2 across three Integrated Assessment Models (IAMs),[25] calculated using discount rates of 5, 3, and 2.5 percent. Estimates at several discount rates are included because the literature indicates that the SC-CO_2 is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context. The fourth value represents the 95th percentile of the SC-CO_2 across the three models, calculated using a 3 percent discount rate. This value is included to represent higher-than-expected impacts from temperature change farther out in the tails of the SC-CO_2 probability distributions.

Low-probability, high-impact events are incorporated into the SC-CO_2 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 in all three models. Treating climate sensitivity probabilistically allows the estimation of SC-CO_2 at potential higher temperature outcomes, which have correspondingly higher projections of damages.

The SC-CO_2 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 IWG estimated the growth rate of the SC-CO_2 directly using the three Integrated Assessment Models rather than assuming a constant annual growth rate. This approach helps ensure that the estimates are internally consistent with other modeling assumptions.

Table 5.3.2-1 lists the SC-CO_2 estimates used in this analysis. Note that the IWG provided estimates of the SC-CO_2 for emissions reductions that occur only through 2050. Because of the long lifetime of CO_2, it is important to account for impacts occurring many years after the time of emissions. Therefore, for any given emissions year, the SC-CO_2 considers impacts through the year 2300. Note that other elements of the climate change analysis in the EIS include emissions reductions between 2050 and 2100 and assess climate impacts (e.g., temperature) to 2100. Table 5.3.2-1 lists global SC-CO_2 estimates in constant 2013 dollars per metric ton of CO_2 emitted. The first three columns of SC-CO_2 estimates are the average SC-

[24] NHTSA inflated the SC-CO_2, which was reported in 2007 dollars, to 2013 dollars, using the annual Implicit Price Deflators for GDP produced by the Bureau of Economic Analysis's (BEA) (see Table 1.1.9 (Implicit Price Deflators for Gross Domestic Product). (Bureau of Economic Analysis 2014).

[25] The three IAMs are DICE, FUND, and PAGE.

CO_2 values across all three of the Integrated Assessment Models used in the IWG analysis. The final column indicates the 95th percentile of the SCC at a 3 percent discount rate across the three models (IWG 2015a). These values are used in the subsequent calculations in this section.

Table 5.3.2-1. Social Cost of Carbon, 2010–2050 (2013 dollars per $MTCO_2$)

Year	Discount Rate and Statistic			
	5% Discount Rate, Average Value ($)	3% Discount Rate, Average Value ($)	2.5% Discount Rate, Average Value ($)	95th Percentile Value at 3% Discount Rate ($)
2010	$11	$34	$55	$94
2015	$12	$39	$61	$115
2020	$13	$46	$68	$135
2025	$15	$50	$75	$151
2030	$18	$55	$80	$167
2035	$20	$60	$86	$184
2040	$23	$66	$92	$201
2045	$25	$70	$98	$216
2050	$29	$76	$100	$232

Notes:
$MTCO_2$ = metric tons of carbon dioxide.

Although the 2013 update to the 2010 SC-CO_2 TSD used new versions of the models that include improvements in the way in which damages are modeled (IWG 2015a), interagency decisions were not revisited with regard to discount rates, emissions scenarios, and other key decisions. The IWG has also indicated that further research is warranted with regard to limitations of the Integrated Assessment Models, which include the quantification of catastrophic and non-catastrophic impacts, the treatment of adaptation and technological change, and the modeling of inter-regional and inter-sectoral linkages (see the 2010 interagency SC-CO_2 TSD (IWG 2010)). The IWG also discussed the need to explore the implications of risk aversion and the imperfect substitution between climate and non-climate goods (at high temperatures) for SC-CO_2 estimation. A recent NAS (2016) Committee report, *Assessment of Approaches to Updating the Social Cost of Carbon: Phase 1 Report on a Near-Term Update*, recommended that in future revisions the IWG should move efforts towards a broader update of the climate system module consistent with the most recent best available science, and also offered recommendations for how to enhance the discussion and presentation of uncertainty in the SC-CO_2 estimates. The Committee recommended against doing a near-term update of the SC-CO_2 estimates.

The IWG expects that over time researchers and modelers will work to fill these gaps and that the SC-CO_2 estimates used by the U.S. Government for regulatory analysis will continue to evolve with improvements in modeling. Additional details on these limitations are discussed in the current SC-CO_2 TSD (IWG 2015a). Even with its limitations, the SC-CO_2 represents a systematic and thorough approach to summarizing a great deal of scientific and economic information. As discussed in a response to comments on the SC-CO_2, separate from this analysis, the IWG continues to recommend the use of the SC-CO_2 estimates (IWG 2015b). Therefore, NHTSA and EPA use these estimates in the Final EIS and FRIA.

5.3.2.2 Social Cost of Non-CO_2 Greenhouse Gases

Elevated atmospheric CO_2 concentration has been the primary driver of recent climate change, largely because CO_2 emissions, weighted by GWP, constitute the majority of human-emitted GHGs today. While other GHGs, such as CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3, also contribute to climate change, the IWG has not developed estimates of the social costs of these gases. Analogous estimates to the IWG's

SC-CO_2 for SC-CH_4 and SC-N_2O were developed by Marten et al. (2014); those estimates are used in this Final EIS to incorporate the social costs of emissions of non-CO_2 gases.[26] The Marten et al. (2014) values for SC-CH_4 have been used in recent EPA RIAs, including for the *Proposed Emission Standards for New and Modified Sources in the Oil and Natural Gas Sector* and for the *Phase 2 HD Fuel Efficiency Improvement Program*, the latter of which also utilizes the SC-N_2O values. As noted above, the use of these values is also supported by the favorable results of a recent EPA peer review of the application of Marten et al. (2014) estimates in regulatory analysis.

Table 5.3.2-2 lists SC-CH_4 and Table 5.3.2-3 lists SC-N_2O estimates from Marten et al. (2014) in constant 2013 dollars per metric ton emitted of CH_4 and N_2O, respectively. Similar to Table 5.3.2-1, the first three columns provide the average social costs across all three of the Integrated Assessment Models used in Marten et al. (2014), presented in costs per metric ton of CH_4 ($MTCH_4$) and N_2O (MTN_2O), respectively. The final column in each table indicates the 95th percentile of the social cost at a 3 percent discount rate across the three models. These values are used in the subsequent calculations in this section.

Table 5.3.2-2. Social Cost of Methane, 2010–2050 (2013 dollars per $MTCH_4$)

Year	Discount Rate and Statistic[a]			
	5% Discount Rate, Average Value ($)	3% Discount Rate, Average Value ($)	2.5% Discount Rate, Average Value ($)	95[th] Percentile Value at 3% Discount Rate ($)
2010	$410	$950	$1,300	$2,600
2015	$490	$1,100	$1,500	$3,100
2020	$590	$1,300	$1,800	$3,500
2025	$710	$1,500	$2,000	$4,100
2030	$830	$1,800	$2,200	$4,600
2035	$990	$2,000	$2,500	$5,400
2040	$1,100	$2,200	$2,900	$6,000
2045	$1,300	$2,500	$3,100	$6,700
2050	$1,400	$2,700	$3,400	$7,300

Notes:

[a] The dollar amounts in these columns are rounded to two significant figures, consistent with the original values in Marten et al. (2014).

$MTCH_4$ = metric tons of methane.

[26] Marten et al. (2014) used the same aggregation method as the IWG's SC-CO_2 to distill the 45 distributions of the SC-CH_4 and SC-N_2O produced for each emissions year into four estimates: the mean across all models and scenarios using a 2.5 percent, 3 percent, and 5 percent discount rate, and the 95th percentile of the pooled estimates from all models and scenarios using a 3 percent discount rate. Marten et al. used lifetimes and radiative efficiencies for CH_4 and N_2O based on the IPCC AR4 values. The authors also adjusted the CH_4 radiative efficiency for CH_4 to account for additional radiative effects due to increases in tropospheric ozone and stratospheric water vapor resulting from methane emissions, using the same adjustment used by in IPCC AR4 for calculating GWP values. Using this approach, Marten et al. (2014) find that the GWP approach provides conservative estimates for the benefits of marginal reductions in CH_4 and N_2O emissions.

Table 5.3.2-3. Social Cost of Nitrous Oxide, 2010–2050 (2013 dollars per MTN_2O)

Year	Discount Rate and Statistic[a]			
	5% Discount Rate, Average Value ($)	**3% Discount Rate, Average Value ($)**	**2.5% Discount Rate, Average Value ($)**	**95th Percentile Value at 3% Discount Rate ($)**
2010	$3,700	$13,000	$20,000	$34,000
2015	$4,400	$14,000	$22,000	$38,000
2020	$5,200	$16,000	$24,000	$43,000
2025	$6,000	$19,000	$26,000	$48,000
2030	$6,900	$21,000	$30,000	$54,000
2035	$8,100	$23,000	$32,000	$60,000
2040	$9,200	$25,000	$35,000	$66,000
2045	$10,400	$27,000	$37,000	$72,000
2050	$12,100	$30,000	$41,000	$79,000

Notes:

[a] The dollar amounts in these columns are rounded to two significant figures, consistent with the original values in Marten et al. (2014).

MTN_2O = metric tons of nitrous oxide.

5.3.3 Methods for Estimating Climate Effects

This EIS estimates and reports four effects of climate change driven by alternative scenarios of projected changes in GHG emissions:

- Changes in CO_2 concentrations
- Changes in global temperature
- Changes in precipitation
- Changes in sea level

The change in GHG emissions is a direct effect of the improvements in HD vehicle fuel efficiency associated with the action alternatives; the four impacts on climate change can be considered indirect effects. Sections 5.3.3.1 through 5.3.3.4 describe the MAGICC modeling, sea-level rise methodology, baseline emissions scenario used to represent the No Action Alternative in this analysis, reference case modeling, and climate sensitivity analysis.

5.3.3.1 MAGICC Modeling

This EIS uses a simple climate model (MAGICC) to estimate the changes in CO_2 concentrations and global mean surface temperature, and uses increases in global mean surface temperature combined with an approach and coefficients from the *IPCC WG1 AR5* (IPCC 2013b) to estimate changes in global precipitation. NHTSA used the publicly available modeling software MAGICC6 (Meinshausen et al. 2011) to estimate changes in key direct and indirect effects. NHTSA used MAGICC6 to incorporate the estimated reductions in emissions of CO_2, CH_4, N_2O, CO, NO_x, SO_2, and VOCs produced by the MOVES model (tailpipe) and the associated estimated changes in upstream emissions using factors obtained from the GREET model and EPA analysis. 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.

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. Applications include the *IPCC WG1 AR5* (IPCC 2013b), where it was used to estimate global mean surface temperature and sea-level rise for simulations of global emissions scenarios that were not run with the more complex atmospheric-ocean general circulation models (AOGCMs) (Meinshausen et al. 2011).
- 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 in this EIS and are best used to provide results for groups of scenarios with much greater differences in emissions.
- MAGICC6 uses updated carbon cycle models that can emulate temperature-feedback impacts on the heterotrophic respiration carbon fluxes.
- MAGICC6 incorporates the science from the *IPCC WG1 AR5;* MAGICC 4.1 was used in the *IPCC WG1 AR4* (IPCC 2007a).[27]

5.3.3.2 Sea-Level Rise

The projected changes in global mean sea level presented in this EIS are estimated based on data from the *IPCC WG1 AR5* (IPCC 2013b).[28] The sea-level rise analysis uses global mean surface temperature data and projections from 1950 to 2100 and global mean sea-level rise projections from 2010 to 2100. These projections are based on the climate ensemble data of the Representative Concentration Pathways (RCP)[29] scenarios for sea level and temperature. Simple equations relating projected changes in sea level to projected changes in temperature are developed for each scenario using a regression model.

The regression models for the RCP4.5 and GCAM6.0 scenarios are developed directly from the RCP4.5 and RCP6.0 data, while the regression model for the GCAM Reference scenario uses a hybrid relation based on the RCP6.0 and RCP8.5 data, as there is no equivalent IPCC scenario. The hybrid relation employs a weighted average of the relationship between RCP6.0 and RCP8.5 sea-level rise and temperature data based on a comparison of the radiative forcings. The temperature outputs of the MAGICC RCP4.5, GCAM6.0, and GCAM Reference simulations are used as inputs to these regression models to project sea-level rise.

5.3.3.3 Global Emissions Scenarios

MAGICC uses long-term emissions scenarios that represent different assumptions about key drivers of GHG emissions. The reference scenario used in this EIS is the GCAM Reference scenario (formerly MiniCAM), which does not assume comprehensive global actions to mitigate GHG emissions. NHTSA

[27] Additional capabilities of MAGICC6 as compared to MAGICC 4.1 include a revised ocean circulation model, improved carbon cycle accounting, direct parameterization of black carbon, organic carbon, and ammonia, and updated radiative forcings. Meinshausen et al. 2011 and Wigley et al. 2009 provide further detail on updates from MAGICC 4.1.

[28] Sea-level rise outputs from MAGICC6 were not used, as this component of the model is still under development.

[29] RCP 2.6, 4.5, 6.0, and 8.5.

selected the GCAM Reference scenario for its incorporation of a comprehensive suite of GHG and pollutant gas emissions, including carbonaceous aerosols and a global context of emissions with a full suite of GHGs and ozone precursors.

The GCAM Reference scenario is based on scenarios presented in Clarke et al. (2007), and was used as the basis for the Representative Concentration Pathway RCP4.5, one of the four emissions scenarios defined for IPCC AR5. 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.

In 2003, the CCSP released the *Strategic Plan for the U.S. Climate Change Science Program* (CCSP 2003), which called for the preparation of 21 synthesis and assessment products (SAPs) addressing a variety of topics on climate change science, GHG mitigation, and adapting to the impacts of climate change. These scenarios used updated economic and technology data along with improved scenario development tools that incorporated knowledge gained over the years since the *IPCC Special Report on Emissions Scenarios* (SRES) (IPCC 2000) was released. The strategy recognized that it would be important to have a consistent set of emissions scenarios so that the whole series of SAPs would have the same foundation. Therefore, one of the earliest products in the series—SAP 2.1, Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations and Review of Integrated Scenario Development and Application (Clarke et al. 2007)—developed 15 global emissions scenarios, corresponding to 5 different emissions trajectories from each of 3 groups using different models (IGSM, MiniCAM, and MERGE). MiniCAM was later renamed GCAM, which is the updated successor to MiniCAM based on improvements in the modeling, and which is the scenario used in this EIS.

Each climate modeling group independently produced a unique emissions 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.

As explained in more detail below, while the direct and indirect impacts analysis uses the GCAM Reference scenario, the cumulative impacts analysis uses the GCAM 6.0 scenario to represent a Reference Case global emissions scenario, because this scenario assumes substantial global actions to address climate change. Sections 5.3.3.3.1 through 5.3.3.3.3 describe the differences among these scenarios and provide the rationale for use in each analysis.

5.3.3.3.1 Scenario Used for the Direct and Indirect Impacts Analysis

The results of the direct and indirect impacts analysis rely primarily on the GCAM Reference scenario to represent a reference case emissions scenario. The GCAM Reference scenario provides a global context for emissions of a full suite of GHGs and ozone precursors. NHTSA chose the GCAM Reference scenario to present the results of the direct and indirect effects analysis based on the following factors:

- The GCAM Reference scenario is a slightly updated version of the scenario developed by the MiniCAM model of the Joint Global Change Research Institute, a partnership between Pacific Northwest National Laboratory and the University of Maryland. The GCAM Reference 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.

- In terms of global emissions of CO_2 from fossil fuels and industrial sources, the GCAM Reference 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 21st century. In essence, the GCAM Reference scenario is a "middle-ground" scenario.
- GCAM Reference was evaluated in the CCSP's SAP 2.1.

EPA also used the GCAM Reference scenario for the Regulatory Impact Analysis of the joint Phase 1 HD National Program Final Rule, as well as the NHTSA and EPA joint final rule that established CAFE and GHG emissions standards for MY 2017–2025 light-duty vehicle fleets.

Each action alternative was simulated by calculating the difference between annual GHG emissions under that action alternative and emissions under the No Action Alternative, and subtracting this change from the GCAM Reference scenario to generate modified global-scale emissions scenarios, which show the effects of the various regulatory alternatives on the global emissions path. For example, CO_2 emissions from HD vehicles in the United States in 2020 under the No Action Alternative are estimated to be 692 $MMTCO_2$;[30] the emissions in 2020 under Alternative 3 (Preferred Alternative) are estimated to be 688 $MMTCO_2$. The difference of 4 $MMTCO_2$ represents the reduction in emissions projected to result from adopting the Preferred Alternative. Global emissions for the GCAM Reference scenario in 2020 are estimated to be 38,017 $MMTCO_2$, and are assumed to incorporate emissions from HD vehicles in the United States under the No Action Alternative. Global emissions under the Preferred Alternative are, therefore, estimated to be 4 $MMTCO_2$ less than this reference level, or approximately 38,013 $MMTCO_2$ in 2020. 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. However, these inconsistencies affect the characterization of each action alternative in equal proportion, so the relative estimates provide a reasonable approximation of the differences in environmental impacts among the action alternatives.

5.3.3.3.2 Scenarios Used for the Cumulative Impacts Analysis

The cumulative impacts analysis relies primarily on the GCAM 6.0 scenario to represent a reference case global emissions scenario that assumes substantial global actions to address climate change, as described in greater detail below. NHTSA chose the GCAM 6.0 scenario as a plausible global emissions baseline due to the potential effects of these reasonably foreseeable actions, and assumes a moderate level of global GHG reductions. This reference case global emissions scenario serves as a baseline against which the climate benefits of the various alternatives in this EIS can be measured. For the analysis in this EIS, each action alternative for cumulative impacts was simulated by calculating the difference between annual GHG emissions under that action alternative and emissions under the No Action Alternative and subtracting this change from the GCAM 6.0 scenario to generate modified global-scale emissions scenarios, which shows the effect of the various alternatives on the global emissions path.

NHTSA used the GCAM 6.0 scenario as the primary global emissions scenario for evaluating climate effects in the cumulative impacts analysis. To evaluate the sensitivity of the results to a reasonable range of alternative emissions scenarios, NHTSA also used the Representative Concentration Pathway (RCP) 4.5 scenario and the GCAM Reference emissions scenario. The RCP4.5 scenario is a more

[30] The emissions estimates in this EIS include GHG emissions resulting from HD vehicle fuel combustion (tailpipe emissions), as well as upstream emissions from the production and distribution of fuel.

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 GCAM 6.0 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. The GCAM 6.0 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 ppm. More specifically, GCAM 6.0 is a scenario that incorporates declines in overall energy use, including fossil fuel use, as compared to the reference case. In addition, GCAM 6.0 includes increases in renewable energy and nuclear energy. The proportion of total energy use supplied by electricity also increases over time due to fuel switching in 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 GCAM 6.0 does not explicitly include specific climate change mitigation policies, it does represent a plausible future pathway of global emissions in response to substantial global action to mitigate climate change.

Using the GCAM 6.0 scenario as described above, total emissions from HD vehicles in the United States in 2020 under the No Action Alternative are estimated to be 692 $MMTCO_2$; emissions in 2020 under the Preferred Alternative are estimated to be 688 $MMTCO_2$. The difference of 4 $MMTCO_2$ represents the reduction in emissions projected to result from adopting the Preferred Alternative. Global CO_2 emissions for the GCAM 6.0 scenario in 2020 are estimated to be 37,522 $MMTCO_2$ and are assumed to incorporate the level of emissions from HD vehicles in the United States under the No Action Alternative. Global emissions under the Preferred Alternative are, therefore, estimated to be 4 $MMTCO_2$ less than this reference level, or 37,518 $MMTCO_2$ in 2020 under the cumulative impacts analysis.

5.3.3.3.3 Past, Present, and Reasonably Foreseeable Future Actions Related to the Cumulative Impacts Analysis

NHTSA chose the GCAM 6.0 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 a moderate reduction in the growth rate of global GHG emissions is reasonably foreseeable in the future.

The initiatives and programs discussed below are those that NHTSA has determined are relevant to its consideration of past, present, or reasonably foreseeable actions to reduce GHG emissions. NHTSA used this scenario to assess the impacts of the action alternatives when reasonably foreseeable reductions in global GHG emissions are taken into account. Although it is not possible to quantify the precise GHG reductions associated with these actions, policies, or programs when taken together (and NHTSA does not attempt to do so), collectively they illustrate an existing and continuing trend of U.S. and global awareness, emphasis, and efforts toward substantial GHG reductions. They imply that future commitments for reductions are probable. Therefore, a scenario that accounts for moderate reductions in the rate of global GHG emissions, such as the GCAM 6.0 scenario, can be considered reasonably foreseeable under NEPA.

United States: Regional Actions

- **Regional Greenhouse Gas Initiative (RGGI)**: Launched in January 1, 2009, RGGI was the first mandatory, market-based effort in the United States to reduce GHG emissions (RGGI 2009). Nine northeastern and Mid-Atlantic States (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont)[31] agreed to cap annual emissions from power plants in the region at 188 $MMTCO_2$ for 2009 through 2011, and 165 $MMTCO_2$ for 2012 through 2013 (RGGI 2014 and Block 2014). In 2013, the RGGI states lowered the Regional Emissions Cap to 91 $MMTCO_2$ for 2014. The RGGI CO_2 cap then declines 2.5 percent per year from 2015 through 2020 (RGGI 2014). By 2020, the program is projected to reduce annual emissions by 80 to 90 million short tons of CO_2 (73 to 82 $MMTCO_2$) below 2005 levels (C2ES 2014d).

- **California Global Warming Solutions Act of 2006 (AB 32)**: California's major initiatives for reducing GHG emissions are implemented under Assembly Bill (AB) 32, which requires California to reduce emissions to 1990 levels by 2020 These initiatives will reduce GHGs from cars, trucks, electricity production, fuels, and other sources. GHG-reduction measures include low carbon fuel standards, a GHG cap-and-trade program, and appliance efficiency standards (CARB 2014). The cap-and-trade program is a key element of AB 32, setting a statewide limit on GHG sources accounting for 85 percent of statewide emissions. The cap-and-trade program took effect in 2013 for electric generation units and large industrial facilities and expanded in 2015 to include ground transportation and heating fuels (C2ES 2014a).

United States: Federal Actions

- **Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources:** In March 2012, EPA proposed a new standard for allowable carbon emissions from new stationary electric power sources. On August 3, 2015, EPA finalized the standards, which apply to any steam generating unit, integrated gasification combined cycle (IGCC), or stationary combustion turbine that commenced construction after January 8, 2014 or commenced reconstruction after June 18, 2014 (EPA 2015b). GHG emissions from new fossil-fuel-fired boilers and IGCC units are capped at 1,400 pounds of CO_2 per MWh gross output over a 12-operating month period. Performance standards for new boilers and new IGCC units are based on partial capture of CO_2 from the unit. New natural-gas-fired stationary combustion units are capped at 1,000 pounds of CO_2 per MWh of gross output (EPA 2015b).
- **Carbon Pollution Emissions Guidelines for Existing Stationary Sources (Clean Power Plan):** EPA released a proposed rule on June 2, 2014 to regulate CO_2 emissions from existing power plants, and finalized the rule on August 3, 2015. Existing units are defined as those that were in operation or had commenced construction as of January 8, 2014. The Final Rule requires states to meet CO_2 emissions targets starting in 2022 through rate-based measures (source-specific emissions performance rates for steam generating unit (IGCC) and stationary combustion turbines or statewide rate-based CO_2 emissions goals) and mass-based measures (statewide mass-based CO_2 emissions goals for existing plants or statewide mass-based goals for both existing and new plants) (EPA 2015c). The rule is expected to reduce CO_2 emissions from existing power plants to 32 percent below 2005 levels by 2030. State rate-based targets proposed by EPA vary widely, from 771 to 1,305 pounds of CO_2 per MWh based on the amount of coal- and gas-fired generation in each state. On February 9, 2016, the U.S. Supreme Court issued a stay decision on the Clean Power Plan, preventing the EPA from implementing the rule until all current lawsuits are resolved.
- **NHTSA and EPA Joint Rule on Fuel Economy and GHG Emissions Standards for Light-Duty Vehicles**: In August 2012, NHTSA and EPA issued joint Final Rules to extend the National Program for fuel economy and GHG emissions standards, generally applying to MY 2017–2025 passenger cars and light trucks. 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

[31] New Jersey was a part of RGGI at its founding, but dropped out of the program in May 2011.

standards under the Clean Air Act (CAA). Vehicles covered by these standards are responsible for almost 60 percent of all U.S. transportation-related GHG emissions. The new standards were projected to reduce CO_2 emissions from the U.S. light-duty vehicle fleet by 3.5 percent per year for MYs 2017–2021, and 5 percent per year for MYs 2022–2025 (NHTSA and EPA 2011). The combined National Program was expected to cut 6 billion metric tons of GHGs over the lifetime of vehicles sold in MYs 2012–2025 (EPA 2012e).

- **NHTSA and EPA Joint Rule on GHG Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Vehicles, MYs 2014–2018**: On September 15, 2011, NHTSA and EPA published the Phase 1 joint Final Rules to establish fuel efficiency and GHG standards for HD vehicles. The rules together comprise a coordinated and comprehensive HD National Program and result in substantial improvements in fuel efficiency and reductions in GHG emissions. 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's Phase 1 mandatory standards for HD vehicles and engines began for MY 2016 vehicles, with voluntary standards for MYs 2014–2015. EPA's mandatory standards for HD vehicles began for MY 2014 vehicles. The agencies estimated 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 built during MYs 2014–2018 (NHTSA 2011).
- **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 regulated 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, increases 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. This increased use of renewable fuels over 30 years, given a zero percent discount rate, is projected to result in a total reduction of 4.5 billion tons CO_2e, equivalent to an annual average reduction of 150 million tons of CO_2e (EPA 2009). As of May 2016, the final renewable fuel standard for 2016 was 10.1 percent (EPA 2016d).
- **United States GHG Emissions Targets Submitted to the UNFCCC**: 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. At the December 2011 United Nations climate change conference in Durban, South Africa (COP-17), the United States reiterated this commitment (U.S. Department of State 2011). On March 31, 2015, the State Department submitted the U.S. Intended Nationally Determined Contribution (INDC) to reduce GHG emissions. The U.S. economy-wide INDC aims to reduce GHG emissions by 26 to 28 percent below 2005 levels by 2025, while also pledging to make best efforts to achieve the higher reduction target of 28 percent below 2005 levels by 2025. In December 2015, the U.S. reaffirmed this target at COP-21 in Paris, France.
- **United States Appliance and Equipment Standards Program**: The National Appliance Energy Conservation Act of 1987 established minimum efficiency standards for many household appliances and is authorized by Congress through several statutes. Since its inception, the program has implemented standards for more than 50 products, which represent about 90 percent of home energy use, 60 percent of commercial building use, and 29 percent of industrial energy use (DOE 2014a). Annual CO_2 savings will reach over 275 million tons of CO_2 by 2020 and the program will have cumulatively avoided 6.8 billion tons by 2030 (DOE 2014b).

<u>International Actions</u>

- **United Nations Framework Convention on Climate Change and the annual Conference of the Parties (COP)**: The UNFCCC is an international treaty signed by many countries around the world (including the United States), which 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).

  Kyoto Protocol: 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 reductions amount to approximately 5 percent of 1990 emissions over the 5-year period 2008 through 2012 (UNFCCC 2014a). The December 2011 COP-17 held in Durban, South Africa, resulted in an agreement to extend the imminently expiring Kyoto Protocol. The "Second Commitment Period" went into effect on January 1, 2013 and runs through December 2020, and requires Parties to reduce emissions by at least 18 percent below 1990 levels by 2020; the Parties in the second commitment period differ from those in the first (UNFCCC 2014a).

  Additional Decisions and Actions: At COP-16, held in Cancun, Mexico 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. At COP-17, the Parties established the "Working Group on the Durban Platform for Enhanced Action" to develop a protocol for mitigating emissions from rapidly developing countries no later than 2015, and to take effect in 2020 (UNFCCC 2014b). As of April 12, 2012, 141 countries had agreed to the Copenhagen Accord, accounting for the vast majority of global emissions (UNFCCC 2010). However, the pledges are not legally binding, and much remains to be negotiated. At COP-18, held in Doha, Qatar in November 2012, the parties also made a long-term commitment to mobilize $100 billion per year to the Green Climate Fund by 2020, which will operate under the oversight of the COP to support climate change-related projects around the world (UNFCCC 2012). At COP-19, held in Warsaw, Poland in November 2013, key decisions were made towards the development of a universal 2015 agreement in which all nations would bind together to rapidly reduce emissions, build adaptation capacity, and stimulate faster and broader action (UNFCCC 2014b). COP-19 also marked the opening of the Green Climate Fund, which began its initial resource mobilization process in 2014 (UNFCCC 2014c). At COP-20, held in Lima, Peru in December 2014, countries agreed to submit INDCs (country-specific GHG mitigation targets) by the end of the first quarter of 2015. COP-20 also increased transparency of GHG reduction programs in developing countries through a Multilateral Assessment process, elicited increased pledges to the Green Climate Fund, made National Adaptation Plans more accessible on the UNFCCC website, and called on governments to increase educational initiatives around climate change (UNFCCC 2014d). At COP-21, the Paris Agreement was adopted, which emphasizes the need to limit global average temperature increase to well below 2°C above preindustrial levels and pursue efforts to limit the increase to 1.5°C. As of April 2016, 177 parties have signed the agreement, which urges countries to commit to a GHG reduction target by 2020 and to submit a new reduction target that demonstrates progress every 5 years thereafter. The UN will analyze progress on global commitments in 2023 and every 5 years thereafter. In order for the Paris Agreement to enter into force, at least 55 countries comprising at least 55 percent of global GHG emissions must ratify the accord (UNFCCC 2015).

- **The European Union GHG Emissions Trading System (ETS)**: In January 2005, the European Union ETS commenced operation as the largest multi-country, multi-sector GHG emissions trading system worldwide (European Union 2014). 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 2005) and covers more than 11,000 energy-intensive installations across the European Union. This represents almost half of Europe's emissions of CO_2 (European Union 2014). These installations include commercial aviation, combustion plants, oil refineries, and iron and steel plants, and factories making cement, glass, lime, brick, ceramics, pulp, and paper (European Union 2014). The EU projects that emissions from sources covered by this program will decrease by 43 percent in 2030 compared to emissions in 2005 (European Union 2014).

- **Fuel Economy Standards in Asia**: Both Japan and China have taken actions to reduce fuel use, CO_2 emissions, and criteria pollutant emissions from vehicles. Japan has invested heavily in research and development programs to advance fuel-saving technologies, has implemented fiscal incentives such as high fuel taxes and differential vehicle fees, and has mandated fuel economy standards based on vehicle weight class (using country-specific testing procedures [Japan 1015/JC08]). As such, Japan adopted efficiency standards for HD vehicles in 2005, with standards to be fully implemented in 2015 (GFEI 2014). In 2015, Japan's Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) finalized new fuel economy standards for light and medium commercial vehicles sold in 2022 at 17.9 km/L (42 mpg), a 23 percent increase from the currently prevailing standard (ICCT 2015). Similarly, China has implemented fuel economy standards, modeled after European Union standards (using the New European Driving Cycle testing methods) (UN 2011). In 2014, the Chinese Ministry of Industry and Information Technology (MIIT) proposed increasing the fleet-average fuel efficiency standard from 6.9 liters per 100 kilometers (L/100km) in 2015 to 5 L/100 km by 2020. The regulation is expected to reduce oil consumption by 348 million barrels and reduce CO_2 emissions by 149 $MMTCO_2e$ in 2030 (ICCT 2014). China has also implemented research and development programs, differential vehicle fees, and technology mandates (UN 2011).

5.3.3.4 Reference Case Modeling Runs

The modeling runs and sensitivity analysis simulate 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. They assume a climate sensitivity of 3°C (5.4°F) for a doubling of CO_2 concentrations in the atmosphere. 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. Global emissions for each action alternative were assumed to be 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 emissions reductions from that alternative). All SO_2 reductions were applied to the Aerosol region 1 of MAGICC, which includes North America.
3. NHTSA used MAGICC6 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 to estimate the increase in both global average precipitation and sea-level rise for each alternative using the global emissions scenario.

5.3.3.5 Sensitivity Analysis

NHTSA performed a sensitivity analysis to examine the effect of various equilibrium climate sensitivities on the results. Equilibrium climate sensitivity 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 compared to pre-industrial atmospheric concentrations (278 ppm CO_2) (IPCC 2013b). 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.

The IPCC AR5 expresses stronger confidence in some fundamental processes in models that determine climate sensitivity than the AR4 (IPCC 2013b). 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 in the range 1.5°C (2.7°F) to 4.5°C (8.1°F) [*high confidence*], *extremely unlikely* less than 1°C (1.8°F) [*high confidence*], and *very unlikely* greater than 6°C (10.8°F) [*medium confidence*] (IPCC 2013b).

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:

1. NHTSA used the GCAM Reference scenario for the direct and indirect impacts analysis and the GCAM 6.0 scenario for 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 WG1 AR5 (IPCC 2013b) 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).
4. For each climate sensitivity value in step 3, NHTSA used MAGICC6 to estimate the resulting changes in CO_2 concentrations and global mean surface temperature, as well as the regression-based analysis to estimate 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. For the direct and indirect impacts analysis, the sensitivity analysis was performed against the GCAM Reference scenario (789 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 GCAM 6.0 (687 ppm in 2100); RCP4.5 (544 ppm in 2100); and GCAM Reference scenario (789 ppm in 2100). Section 5.4.2.3.5 presents the results of the cumulative impacts sensitivity analysis for these different global emissions 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, 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 2009 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 2009 citing NRC 2002).

NHTSA's assessment of tipping points and abrupt climate change is largely based on an analysis of recent climate change science synthesis reports: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013b) and Climate Change Impacts in the United States: The Third National Climate Assessment (GCRP 2014). 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 emissions 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 5.5.2.10 of this EIS. 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.

5.4 Environmental Consequences

This section describes projected impacts on climate under the Final Action and the alternatives considered. Using the methodologies described in Section 5.3, NHTSA modeled the effects of the Final Action and alternatives on atmospheric CO_2 concentrations, temperature, precipitation, and sea-level rise. To calculate the incremental benefits of the Final Action and alternatives, NHTSA examined the direct and indirect impacts of the action alternatives, which were developed by using the analytical methodologies described in Chapter 2. The methodologies used to estimate the climate-related impacts of the Final Action and alternatives are summarized in Section 5.3.

Section 5.4 is organized into Section 5.4.1, *Direct and Indirect Impacts*, and Section 5.4.2, *Cumulative Impacts*. Within each, there are sub-sections for greenhouse gas emissions, the social cost of carbon, and impacts on climate change indicators. The analysis of direct and indirect impacts in Section 5.4.1 is based on a scenario under which there are no other major global actions to reduce GHGs. This analysis assumes that there is some growth in HD vehicle fuel efficiency in the absence of this rulemaking, with no ongoing improvements in new vehicle fuel efficiency after the final year of stringency increases. This section presents the results of the analysis of the alternatives. The analysis compares the alternatives to the current climate trajectory, independent of other actions.

The analysis of cumulative impacts in Section 5.4.2 measures the combined impacts of market-based incentives for improving HD vehicle fuel efficiency after 2018 and the HD vehicle fuel efficiency improvements resulting directly or indirectly from the Final Action and alternatives. This analysis generally assumes no improvement in future HD vehicle fuel efficiency in the absence of this rulemaking and no ongoing improvements in new vehicle fuel efficiency after the final year of stringency increases. For assessing climate impacts, the analysis in Section 5.4.2 is broader in that it addresses the effects of the standards in concert with the effects of other past, present, and reasonably foreseeable future actions that affect the current climate trajectory.

5.4.1 Direct and Indirect Impacts

This section describes the environmental consequences of the Final Action and alternatives on GHG emissions and climate effects.

5.4.1.1 Greenhouse Gas Emissions

Using the methodology described in Section 5.3, NHTSA estimated projected emissions reductions under the Final Action and alternatives for 2018 through 2100. The emissions reductions in the following discussion represent the differences in total annual emissions in future years of U.S. HD vehicles in use under the No Action Alternative and each action alternative. 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 under each alternative. Because CO_2 accounts for such a large fraction of total GHGs emitted during fuel production and use—more than 97 percent, even after accounting for the higher GWPs of other GHGs—NHTSA's consideration of GHG impacts focuses on reductions in CO_2 emissions expected under the action alternatives. 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 and Figure 5.4.1-1 show total U.S. HD vehicle CO_2 emissions under the No Action Alternative and emissions reductions that would result from each of the action alternatives from 2018 to 2100. U.S. HD vehicle emissions for this period range from a low of 54,500 $MMTCO_2$ under Alternative 5 up to 67,500 $MMTCO_2$ under the No Action Alternative. Compared to the No Action Alternative, projected emissions reductions from 2018–2100 under the action alternatives range from 3,800 to 13,000 $MMTCO_2$.

Table 5.4.1-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles, 2018–2100 by Alternative, Direct and Indirect Impacts[a]

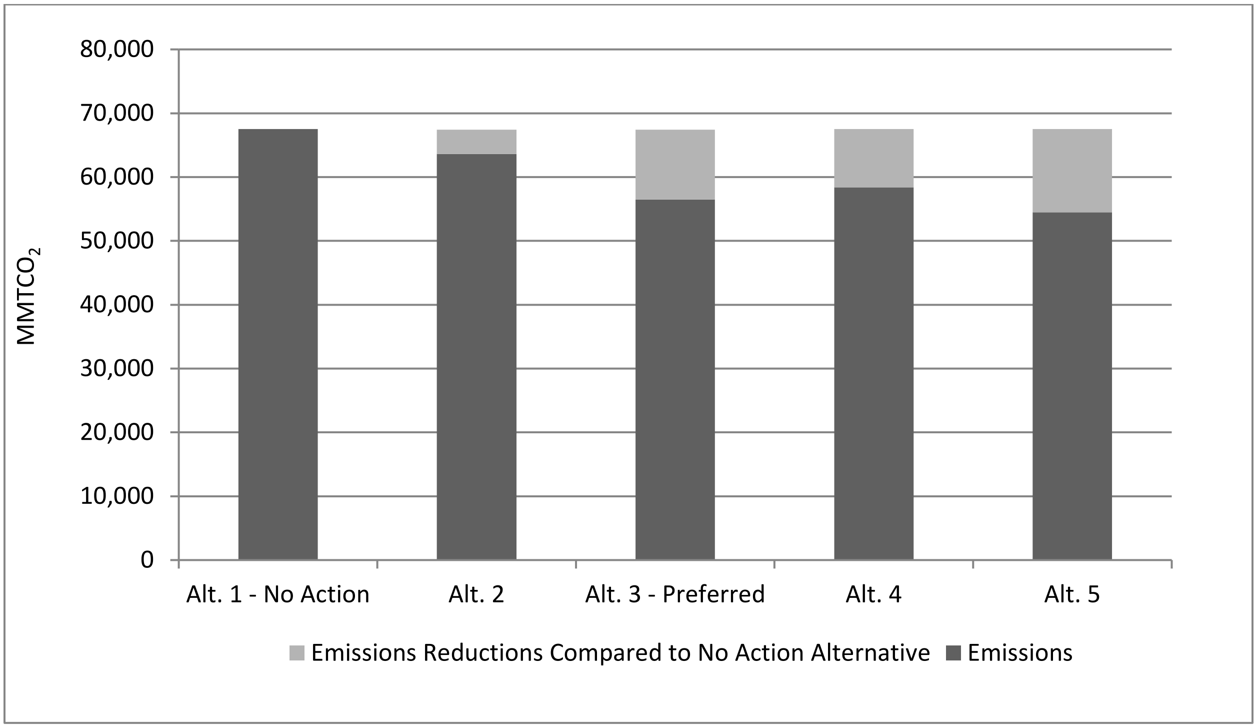
Alternative	Total Emissions	Emissions Reductions Compared to No Action	Percent (%) Emissions Reductions Compared to No Action Emissions
Alt. 1 – No Action	67,500		
Alt. 2	63,600	3,800	6%
Alt. 3 – Preferred	56,500	10,900	16%
Alt. 4	58,400	9,100	13%
Alt. 5	54,500	13,000	19%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.

$MMTCO_2$ = million metric tons of carbon dioxide.

Figure 5.4.1-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles, 2018 to 2100 by Alternative, Direct and Indirect Impacts



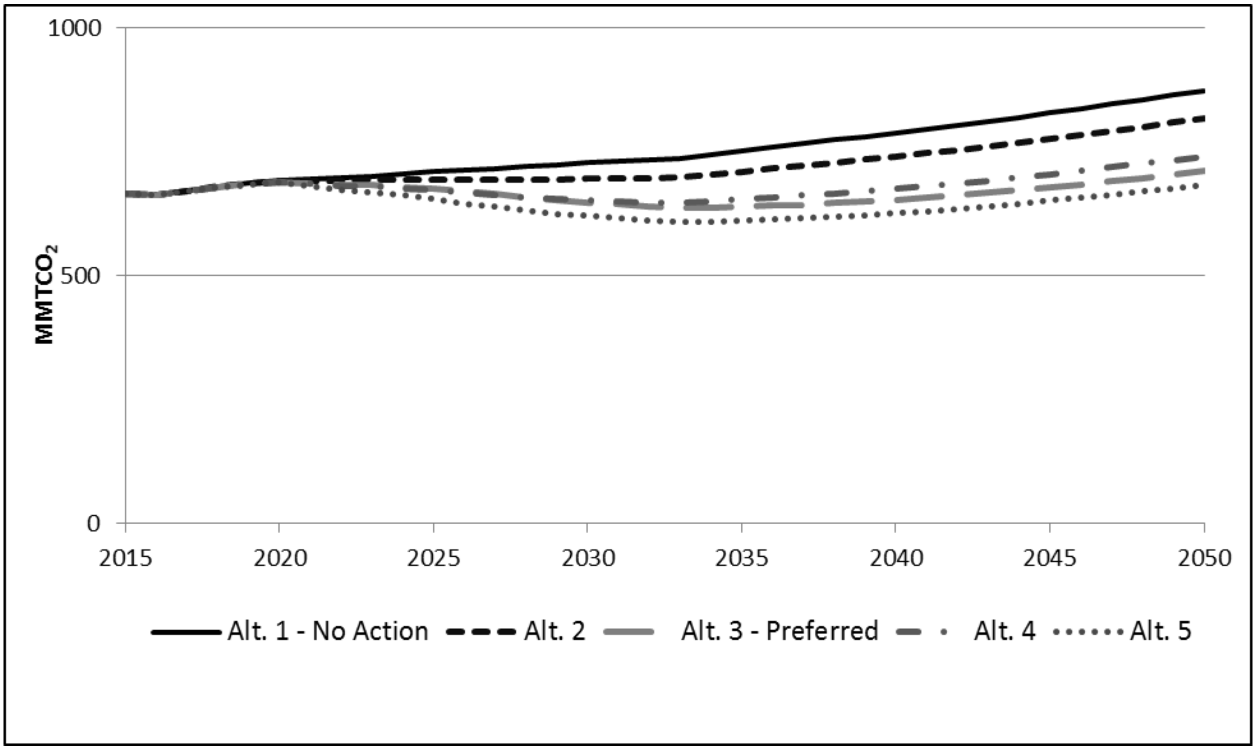
$MMTCO_2$ = million metric tons of carbon dioxide.

Compared to total global emissions of 5,063,078 $MMTCO_2$ over this period (projected by the GCAM Reference scenario), this rulemaking is expected to reduce global CO_2 emissions by approximately 0.1 to 0.3 percent from projected levels under the No Action Alternative.

To get a sense of the relative impact of these reductions, it can be helpful to consider emissions from HD vehicles in the context of emissions projections from the transportation sector and expected or stated goals from existing programs designed to reduce CO_2 emissions. HD vehicles currently account for 7.6 percent of CO_2 emissions in the United States. The action alternatives reduce total CO_2 emissions from U.S. HD vehicles by a range of 6 to 19 percent in the period from 2018 to 2100 compared to the No Action Alternative. Compared to total U.S. CO_2 emissions of 7,193 $MMTCO_2e$ from all sources by the end of the century projected by the GCAM Reference scenario (Thomson et al. 2011), the action alternatives would reduce total U.S. CO_2 emissions by a range of 0.7 to 2.4 percent in 2100.[32] Figure 5.4.1-2 shows the projected annual emissions from U.S. HD vehicles under the alternatives.

[32] 2095 is the last year emissions data is available from GCAM Reference.

Figure 5.4.1-2. Projected Annual CO_2 Emissions ($MMTCO_2$) from All HD Vehicles by Alternative, Direct and Indirect Impacts



CO_2 = carbon dioxide; $MMTCO_2$ = million metric tons of carbon dioxide.

Table 5.4.1-2 shows that under the No Action Alternative, total CO_2, CH_4, and N_2O emissions from HD vehicles in the United States are projected to substantially increase between 2018 and 2100 in the direct/indirect impacts analysis. Growth in the number of HD vehicles in use throughout the United States, combined with assumed increases in their average use, is projected to result in a growth in VMT. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles.

Table 5.4.1-2 also illustrates that each action alternative would reduce HD vehicle 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. The more stringent action alternatives generally result in greater emissions reductions compared to the No Action Alternative. Alternative 4 is an exception, as Alternative 4 is less stringent than Alternative 3 in this Final EIS for some vehicle categories. This change from the Draft EIS reflects Final EIS standards for Alternative 3 that are more stringent than the Draft EIS proposed standards for Alternative 3, whereas standards for Alternative 4 in this Final EIS are the same as the Alternative 4 standards in the Draft EIS (*see* Section 2.2).

Table 5.4.1-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All HD Vehicles by Alternative, Direct and Indirect Impacts[a]

GHG and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon dioxide (CO_2)					
2020	692	690	688	688	687
2040	787	739	652	674	625
2060	868	812	707	736	679
2080	862	807	702	731	675
2100	801	750	653	680	627
Methane (CH_4)					
2020	18.96	18.88	18.84	18.83	18.81
2040	21.52	20.25	18.03	18.55	17.32
2060	23.65	22.18	19.50	20.20	18.76
2080	23.49	22.02	19.36	20.06	18.63
2100	21.85	20.48	18.01	18.66	17.33
Nitrous oxide (N_2O)					
2020	2.31	2.29	2.29	2.29	2.28
2040	2.31	2.22	2.09	2.11	2.04
2060	2.51	2.40	2.24	2.28	2.20
2080	2.49	2.39	2.23	2.26	2.18
2100	2.32	2.22	2.07	2.10	2.03
Total (all GHGs)					
2020	713	711	709	709	708
2040	811	762	672	695	645
2060	894	837	729	759	700
2080	888	831	723	754	695
2100	826	773	673	701	647

Notes:

[a] Emissions from 2051–2100 were scaled using the rate of change for the U.S. transportation fuel consumption from the GCAM Reference scenario. These assumptions project a slight decline over this time period.

$MMTCO_2e$ = million metric tons carbon dioxide equivalent.

5.4.1.1.1 Comparison to the 2020 and 2025 U.S. GHG Targets Submitted to the United Nations Framework Convention on Climate Change

These results can be viewed in light of U.S. 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. On March 31, 2015, President Obama submitted an “Intended Nationally Determined Contribution” (INDC) to reduce U.S. GHG emissions in the range of 26 to 28 percent below 2005 levels by 2025. In December 2015, the U.S. reaffirmed this target at COP-21 in Paris, France. The INDC also pledges that the United States will make best efforts to achieve the higher reduction target of 28 percent below 2005 levels by 2025.

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. HD vehicle sector in 2020 and 2025 are projected to be above 2005 levels. Therefore, assuming the same percentage decrease in emissions would need to be achieved from all sectors in order to reach the president's target, these reductions in emissions alone would not reduce total HD vehicle emissions to 17 percent below their 2005 levels by 2020, or 26 to 28 percent below 2005 levels by 2025.

The president's targets outlined above do not specify that every emitting sector of the economy must contribute equally proportional emissions reductions. Thus, smaller emissions reductions in the HD vehicle sector can be compensated for by larger reductions in other sectors. In addition, the action of setting fuel economy standards does not directly regulate total emissions from HD vehicles. NHTSA's authority to promulgate new HD vehicle fuel efficiency standards does not allow the agency to regulate certain other factors affecting emissions, such as HD vehicle driving habits or use trends; NHTSA cannot, for example, control VMT. Under all of the alternatives, growth in the number of HD vehicles in use throughout the United States, combined with assumed increases in their average use (annual VMT per vehicle) due to economic improvement and a variety of other factors, is projected to result in growth in HD vehicle VMT.

This projected growth in travel between 2020 and 2050 more than offsets the effect of improvements in HD vehicle fuel efficiency for Alternatives 2, 3, and 4 due to increases in fuel consumption from HD vehicles. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from HD vehicles. Nevertheless, this rulemaking is an important component of a variety of actions in various sectors to meet the U.S. GHG targets.

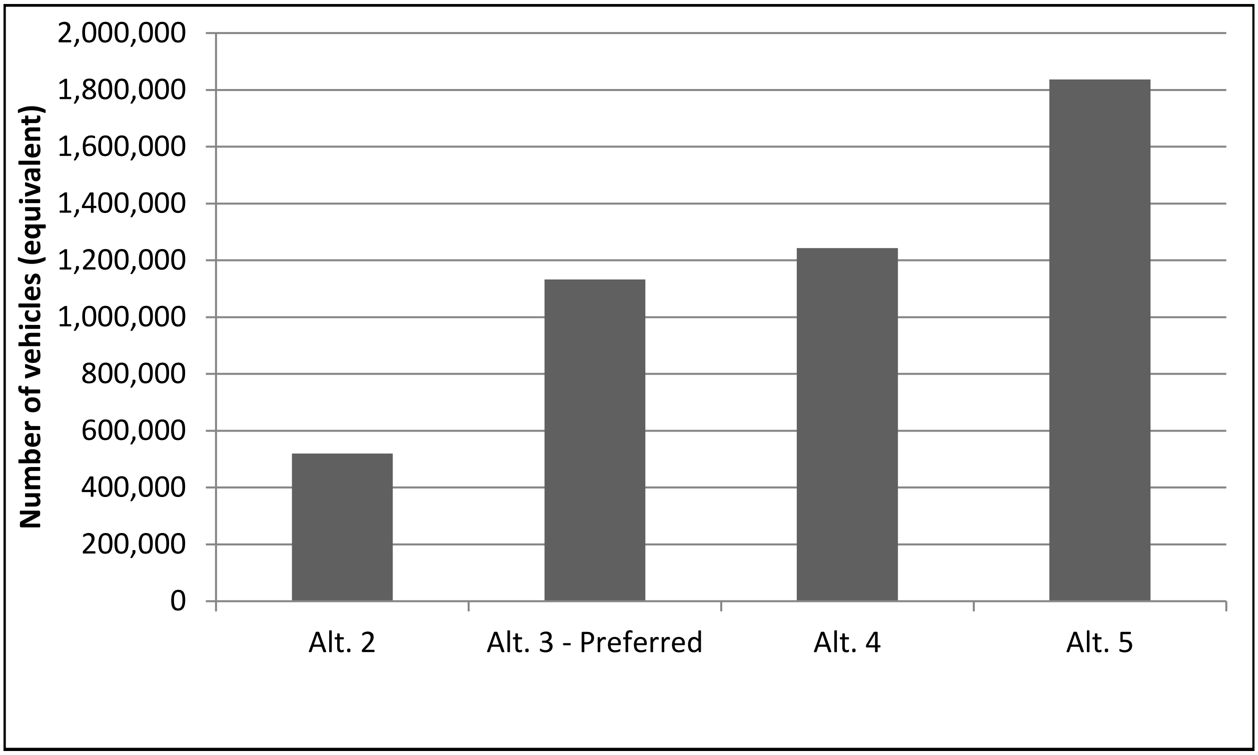
5.4.1.1.2 Comparison to Annual Emissions from HD Vehicles

As an illustration of the fuel savings projected under the action alternatives, Figure 5.4.1-3 expresses the CO_2 reductions under each action alternative in 2025 as the equivalent number of HD vehicles that would produce those emissions in that year. The emissions reductions under the action alternatives are equivalent to the annual emissions of between 519,000 HD vehicles (Alternative 2) and 1.84 million HD vehicles (Alternative 5) in 2025, compared to the annual emissions that would occur under the No Action Alternative. Emissions reductions in 2025 under the Preferred Alternative are equivalent to annual emissions of 1.13 million HD vehicles.

These annual CO_2 reductions, their equivalent in HD vehicles, and differences among alternatives grow larger in future years as older HD vehicles continue to be replaced by newer ones that meet the increasingly stringent fuel efficiency standards required under each alternative.[33]

[33] The HD 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 HD vehicle accounts for 30.63 metric tons of CO_2 in 2025 based on MOVES, the GREET model, and EPA analysis.

Figure 5.4.1-3. Number of HD Vehicles Equivalent to CO_2 Reductions in 2025, Compared to the No Action Alternative, Direct and Indirect Impacts



5.4.1.1.3 Comparison to GHG Reduction Programs in the United States

To understand the projected emissions reductions from the alternatives better, the reductions can also be compared to existing programs that have been designed to reduce GHG emissions in the United States.

On August 3, 2015, EPA finalized a rule, known as the Clean Power Plan, under Section 111(d) of the CAA to regulate CO_2 emissions from existing power plants. EPA published the rule in the *Federal Register* on October 23, 2015. The rule will cover about 3,000 coal- and natural gas-fired electric generating units and is expected to reduce CO_2 emissions from existing power plants to 32 percent below 2005 levels in the year 2030, equivalent to 789 $MMTCO_2e$ (EPA 2015d and EPA 2015e). On February 9, 2016, the U.S. Supreme Court issued a stay decision on the Clean Power Plan, preventing the EPA from implementing the rule until all current lawsuits are resolved.

California's major initiatives for reducing GHG emissions are implemented under AB 32, which requires California to reduce emissions to 1990 levels by 2020 (equivalent to a reduction of 78 $MMTCO_2e$ in 2020 below the "business-as-usual" baseline). GHG reduction measures include low-carbon fuel standards, a GHG cap-and-trade program, and appliance efficiency standards (CARB 2014). The cap-and-trade program is a key element of AB 32, setting a statewide limit on GHG sources accounting for 85 percent of statewide emissions. The cap-and-trade program took effect in 2013 for electric generation units and large industrial facilities and expands in 2015 to include ground transportation and heating fuels (C2ES 2014a).

Elsewhere in the United States, the nine RGGI member states in the northeast and mid-Atlantic regions set a goal to cap annual CO_2 emissions from power plants in the northeast beginning in 2009 (C2ES 2014d). For example, the RGGI set a Regional Emissions Cap of 91 $MMTCO_2$ for 2014; the cap then declines 2.5 percent per year from 2015 to 2020 (RGGI 2014). By 2020, the program is projected to reduce annual emissions by 80 to 90 million short tons (73 to 82 $MMTCO_2$) below 2005 levels (C2ES 2014d).

In comparison, the Final Action and alternatives are projected to reduce CO_2 emissions by 32 to 110 $MMTCO_2e$ in the direct/indirect analysis in 2030 (depending on the alternative), with emissions levels representing a 4.3 to 14.6 percent reduction from the baseline emissions for U.S. HD vehicles in 2030.

Note that comparisons between this rulemaking and other programs are not straightforward, given the difference in the periods over which reductions are estimated and differences in the emissions reference case. In general, the longer the period, the greater the potential emissions reductions. Table 5.4.1-3 summarizes the emissions reductions for the Final Action and alternatives, EPA's Clean Power Plan, AB 32, and the RGGI program.

Table 5.4.1-3. Comparison of GHG Emissions Impacts between the Phase 2 HD Fuel Efficiency Improvement Program and GHG Reduction Initiatives in the United States

Program	Emissions Reduction Year	Baseline from Which Reductions Are Estimated	Range of Reductions ($MMTCO_2e$)
Phase 2 HD Standards, Direct and Indirect Analysis	2030	Business as usual baseline	32–110
Clean Power Plan under Section 111(d) of the Clean Air Act[a]	2030	Annual emissions in 2005	789
Regional GHG Initiative (RGGI)[b]	2020	Annual emissions in 2005	73–82
California Global Warming Solutions Act (AB 32)[c]	2020	Business as usual baseline	78

Notes:

[a] EPA 2015d.

[b] C2ES 2014d projects emissions reductions from RGGI to be between 80 and 90 million short tons of CO_2 from 2005 levels (value in the table is converted to metric tons).

[c] CARB 2014 caps emissions under AB 32 at 431 $MMTCO_2e$ in 2020, compared with BAU emissions in 2020 of 509 $MMTCO_2e$.

$MMTCO_2e$ = million metric tons of carbon dioxide equivalent; GHG = greenhouse gas.

Two features of these comparisons are important to emphasize. First, total emissions from the sources covered under the Clean Power Plan under Section 111(d) of the CAA, AB 32, and RGGI 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 HD vehicles covered under this rulemaking are projected to increase over the long term under Alternatives 2, 3, and 4 due to increases in VMT. However, each of the action alternatives would still result in large-scale reductions of total GHG emissions as compared to the No Action Alternative. Second, these projections are estimates only, and the scope of these climate programs differs from the scope of this rulemaking in terms of geography, sector, and purpose.

In this case, the comparison of emissions reductions from the alternative fuel economy standards to emissions reductions associated with other programs is intended to benefit decisionmakers by providing relative benchmarks, rather than absolute metrics, for selecting among alternatives.

5.4.1.2 Social Cost of Greenhouse Gases

Table 5.4.1-4 lists the benefits of the Final Action and alternatives in terms of reduced monetized damages for CO_2, CH_4, and N_2O. NHTSA derived the net present value of the benefits reported in these tables by: (1) using the estimates of the SC-CO_2, SC-CH_4, and SC-N_2O per ton reported previously in Section 5.3.2, (2) applying each future year's SC-CO_2, SC-CH_4, and SC-N_2O estimate (per ton) to the projected reduction in CO_2, CH_4, and N_2O emissions, respectively, 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 the estimated reductions in the SC-CO_2, SC-CH_4, and SC-N_2O for each year from 2018 to 2050. For internal consistency, the annual benefits are discounted to net present value terms using the same discount rate as each social cost 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.

Table 5.4.1-4. Reduced Monetized Damages from CO_2, CH_4, and N_2O Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative (net present value in 2015 in millions of 2013 dollars), Direct and Indirect Impacts[a]

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
Alt. 2	$7,806	$35,837	$56,909	$108,878
Alt. 3 – Preferred	$20,930	$96,725	$153,809	$294,139
Alt. 4	$18,350	$84,291	$133,870	$256,126
Alt. 5	$26,383	$121,184	$192,464	$368,253

Notes:

[a] Includes emissions reductions that occur between 2017 and 2050 as a result of Phase 2 HD standards.

CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide.

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 5.4.1.3.5 presents the sensitivity analysis. The impacts of the Final Action and alternatives on global mean surface temperature, precipitation or sea-level rise are small compared to the expected changes associated with the emissions trajectories in the GCAM Reference 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-lasting. The combined impact of these emissions reductions with emissions reductions from other sources can have large health, societal, and environmental benefits.

MAGICC6 is a simple climate model well calibrated to the mean of the multi-model ensemble results for four of the most commonly used emissions scenarios—RCP 2.6 (low), RCP 4.5 (medium), RCP 6.0 (medium-high), and RCP8.5 (high) from the IPCC RCP series—as shown in Table 5.4.1-5.[34] As the table shows, the results of the model runs developed for this analysis agree relatively well with IPCC estimates for both CO_2 concentrations and surface temperature.

[34] NHTSA used the MAGICC default climate sensitivity of 3.0 °C (5.4 °F).

Table 5.4.1-5. Comparison of MAGICC Modeling Results and Reported IPCC Results[a,b]

Scenario	CO_2 Concentration (ppm)		Global Mean Increase in Surface Temperature (°C)	
	IPCC WGI (2100)	MAGICC (2100)	IPCC WGI (2081—2100)	MAGICC (2100)
RCP 2.6	421	426	1.0	1.1
RCP 4.5	538	544	1.8	2.1
RCP 6.0	670	674	2.2	2.6
RCP 8.5	936	938	3.7	4.2

Notes:

[a] Source: IPCC 2013b.

[b] The IPCC values represent the average of the 5 to 95 percent range of global mean surface air temperature.

CO_2 = carbon dioxide; ppm = parts per million; °C = degrees Celsius; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; IPCC = Intergovernmental Panel on Climate Change; RCP = Representative Concentration Pathways; WGI = Working Group 1.

As discussed in Section 5.3.3.3.1, NHTSA used the GCAM Reference scenario to represent the No Action Alternative in the MAGICC modeling runs. CO_2 concentrations range from 788.0 ppm under Alternative 5 to 789.1 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 5.5.2), this leads to small differences in these effects. Even though these effects are small, they occur on a global scale and are long-lasting.

Table 5.4.1-6. CO_2 Concentrations, Global Mean Surface Temperature Increase, and Sea-Level Rise (GCAM Reference) by Alternative, Direct and Indirect Impacts[a]

Totals by Alternative	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b, c]			Sea-level rise (cm)[b, d]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100
Alt. 1 – No Action	479.0	565.4	789.1	1.287	2.008	3.484	22.87	36.56	76.28
Alt. 2	479.0	565.3	788.8	1.287	2.008	3.483	22.87	36.56	76.26
Alt. 3 – Preferred	478.9	565.0	788.2	1.287	2.006	3.480	22.87	36.55	76.21
Alt. 4	478.9	565.1	788.3	1.287	2.007	3.481	22.87	36.55	76.22
Alt. 5	478.9	564.9	788.0	1.286	2.006	3.480	22.87	36.54	76.19
Reductions Under Alternatives									
Alt. 2	0.1	0.1	0.3	0.000	0.001	0.001	0.00	0.01	0.03
Alt. 3 – Preferred	0.1	0.4	1.0	0.001	0.002	0.004	0.00	0.01	0.07
Alt. 4	0.1	0.3	0.8	0.000	0.001	0.003	0.00	0.01	0.06
Alt. 5	0.2	0.5	1.1	0.001	0.002	0.004	0.00	0.02	0.09

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.

[c] Temperature changes reported as 0.000 are more than zero but less than 0.001.

[d] Sea-level rise changes reported as 0.00 are more than zero but less than 0.01.

CO_2 = carbon dioxide; °C = degrees Celsius; ppm = parts per million; cm = centimeters; GCAM = Global Change Assessment Model.

5.4.1.3.1 Atmospheric CO_2 Concentrations

As Figure 5.4.1-4 and Figure 5.4.1-5 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 Figure 5.4.1-5, the reduction in CO_2 concentrations by 2100 under Alternative 5 is more than three times that of Alternative 2.

Figure 5.4.1-4. Atmospheric CO_2 Concentrations by Alternative, Direct and Indirect Impacts

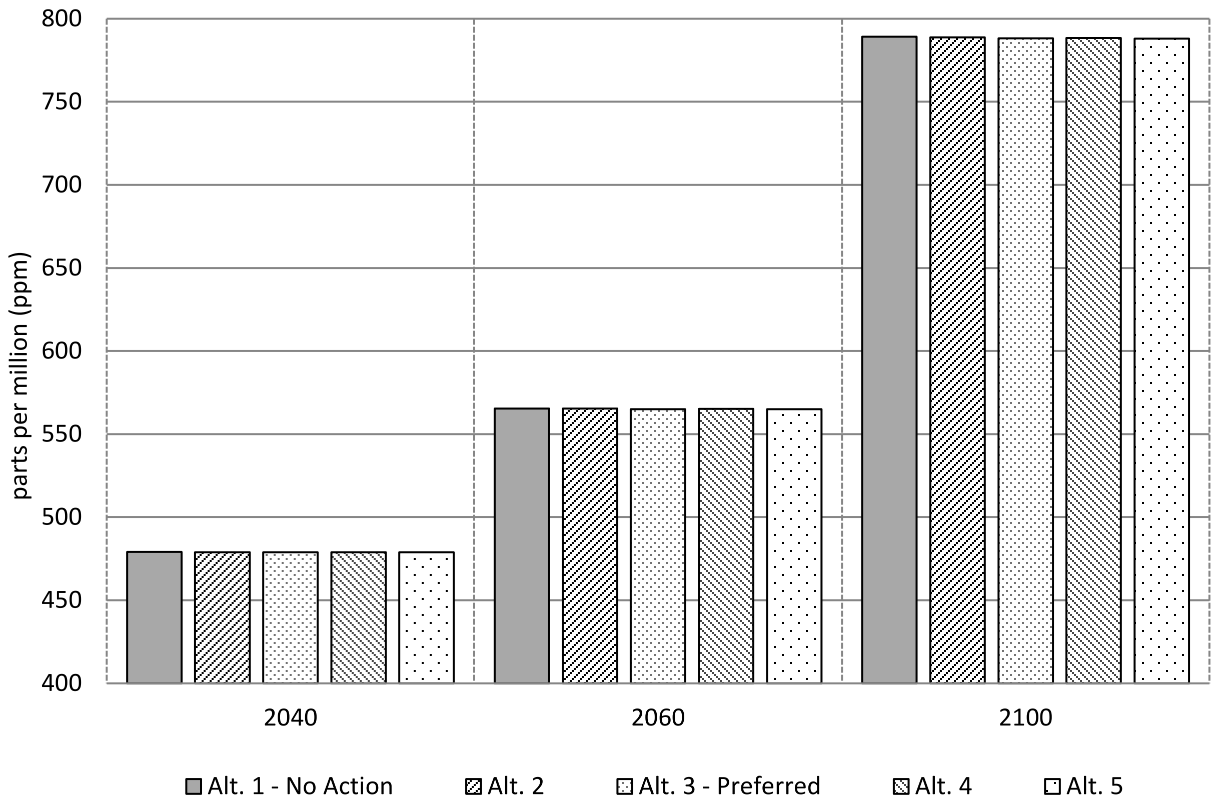
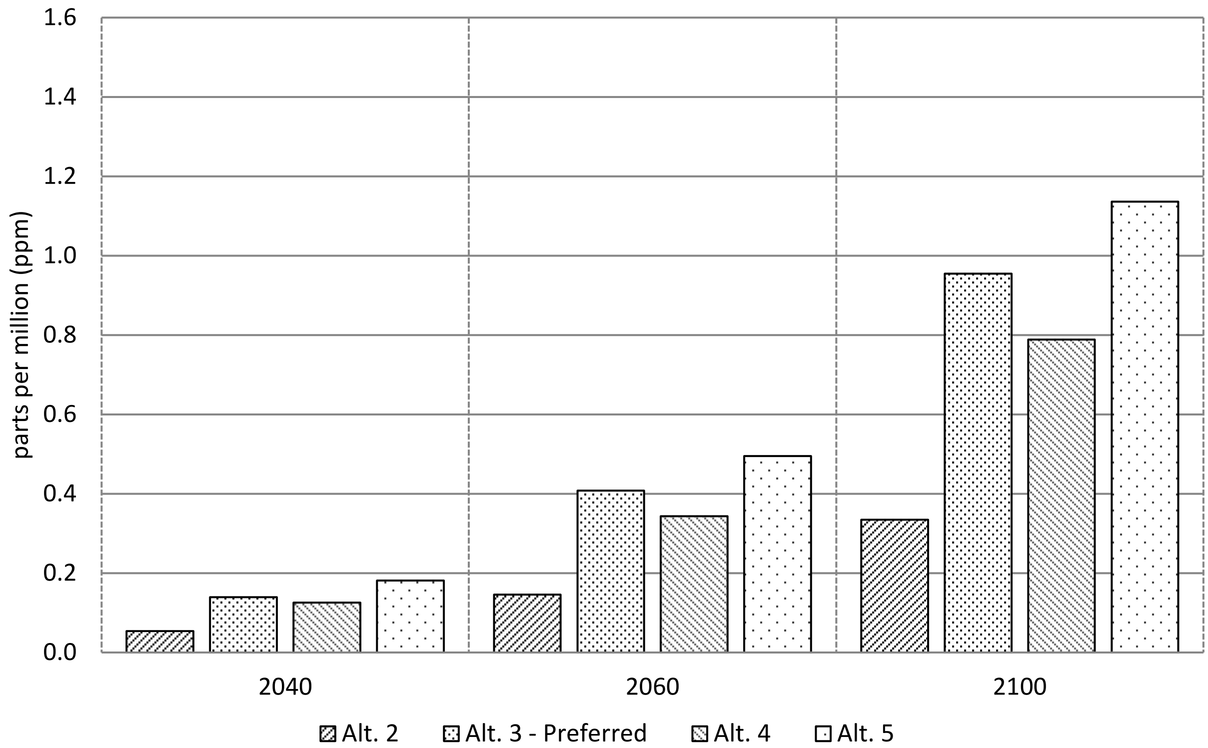


Figure 5.4.1-5. Reduction in Atmospheric CO_2 Concentrations Compared to the No Action Alternative, Direct and Indirect Impacts



5.4.1.3.2 Temperature

Table 5.4.1-6 lists MAGICC simulations of mean global surface air temperature increases. Under the No Action Alternative in all analyses, global surface air temperature is projected to increase from 1986–2005 average levels by 1.29°C (2.32°F) by 2040, 2.01°C (3.61°F) by 2060, and 3.48°C (6.27°F) by 2100.[35] The differences among the reductions in baseline temperature increases projected to result from the various action alternatives are small compared to total projected temperature increases, which are shown in Figure 5.4.1-6. For example, in 2100 the reduction in temperature increase compared to the No Action Alternative ranges from 0.001°C (0.002°F) under Alternative 2 to 0.004°C (0.008°F) under Alternative 5. Figure 5.4.1-7 also illustrates that reductions in the growth of projected global mean surface temperature under each action alternative compared to the No Action Alternative are anticipated to be small compared to total projected temperature increases. 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 5. As shown in Figure 5.4.1-7, the reduction in the projected growth in global temperature under Alternatives 3 and 5 is more than three times as large as that under Alternative 2 in 2100.

[35] 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 5.4.1-6. Global Mean Surface Temperature Increase by Alternative, Direct and Indirect Impacts

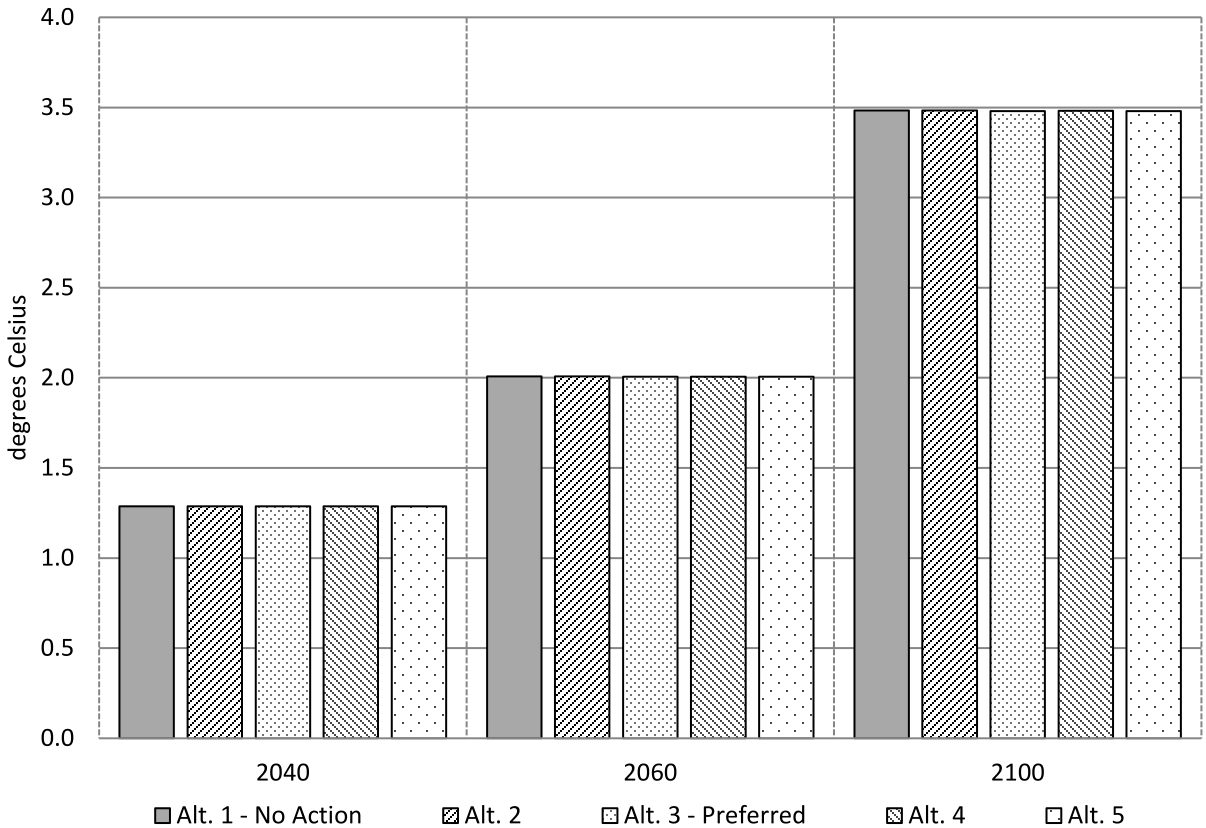


Figure 5.4.1-7. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative, Direct and Indirect Impacts

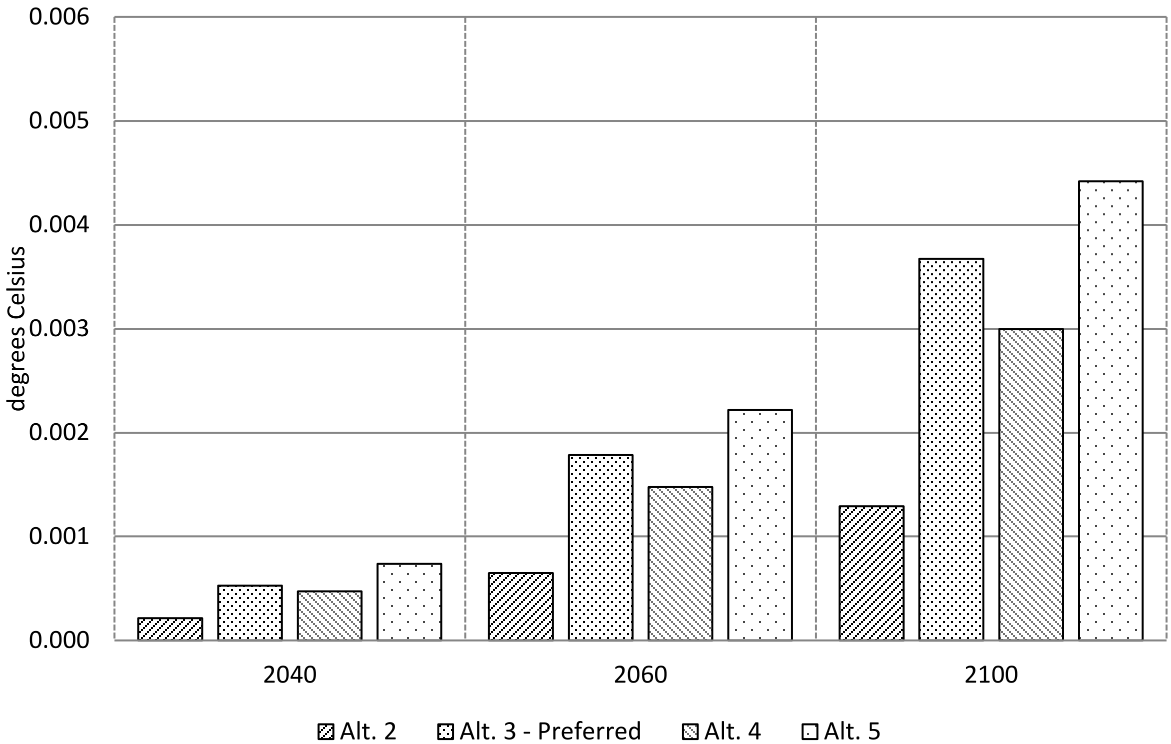


Table 5.4.1-7 summarizes the regional changes in warming and seasonal temperatures presented in the IPCC Fifth Assessment Report (AR5). At this time, quantifying the changes in regional climate as a result of the action alternatives is not possible due to the limitations of existing climate models, but the action alternatives would be expected to reduce the regional impacts in proportion to reductions in global mean surface temperature.

Table 5.4.1-7. Regional Changes to Warming and Seasonal Temperatures Summarized from the IPCC Fifth Assessment Report

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Africa	Northern Africa and Northern Sahara	*Very likely* increase in mean annual temperature[a,b] *Likely* increase throughout region to be higher than global mean annual warming[e]	*Likely* greater warming at night compared to day resulting in a reduction in future temperature rise[e]
	East Africa	*Very likely* increase in mean annual temperature[a,b]	
	Southern Africa	*Very likely* increase in mean annual temperature[a,b] *Likely* higher mean land surface warming than global average	

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
	Western Africa	*Very likely* increase in mean annual temperature[a,b]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, and increase in more frequent droughts
Mediterranean and Europe	Northern Europe	*Very likely* increase in mean annual temperature, *likely* greater increase in winter temperature than in Central or Southern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves (though little change over Scandinavia)
	Central Europe	*Very likely* increase in mean annual temperature, *likely* greater increase in summer temperature than in Northern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves
	Southern Europe and Mediterranean	*Very likely* increase in mean annual temperature, *likely* greater increase in summer temperature than in Northern Europe	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* more frequent heat waves
Asia	Central Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Northern Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Eastern Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	West Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	South Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeast Asia	*Likely* increase in mean annual temperature[a,b,c,d]	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
North America	Northern regions/Northern North America	*Very likely* increase in mean annual temperature[a,b]	Minimum winter temperatures are *likely* to increase more than the average
	Southwest	*Very likely* increase in mean annual temperature[a,b]	
Central and South America	Central America and the Caribbean	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Southeastern South America	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Amazon Region	*Very likely* increase in temperatures, greater than in other Central and South American locations	*Likely* increase in hot days and decrease in cool days, *very likely* increase in warm nights and decrease cold nights, *likely* increase in frequency and duration of heat waves
	Andes Region	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
	Northeastern Brazil	*Very likely* increase in temperatures	*Likely* increase in hot days and warm nights, decrease in cool days and cold nights, increase in frequency and duration of heat waves
Australia and New Zealand	Southern Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	Southwestern Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	Rest of Australia	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves
	New Zealand	*Virtually certain* increase in mean annual temperature	*Very likely* increase in hot days and warm nights, decrease in cool days and cold nights, *likely* increase in frequency and duration of heat waves

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
Polar Regions	Arctic	*Likely* that surface temperatures will be strongly influenced by anthropogenic forcing by mid-century	
	Antarctic	*Very likely* to increase lower than global mean	
Small Islands		*Very likely* increase in temperature	

Note: Information is omitted from the table where no data was available from AR5.

Regional changes are provided for end-of-century compared to today's baseline, unless otherwise noted. Future modeled change can vary depending on a number of factors such as the concentration pathways used to drive the climate models (e.g., the amount of CO_2 emitted each year around the globe). The following superscripts were used to distinguish the various concentration pathways associated with specific findings:

[a] RCP2.6

[b] RCP8.5

[c] RCP4.5

[d] RCP6.0

[e] SRES A1B

No superscripts were used for those findings where the concentration pathways were not identified.

Source: IPCC 2013b.

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 more water evaporation, which causes more water vapor to be available for precipitation (EPA 2009). Increased evaporation leads to increased precipitation in areas where surface water is sufficient, such as over oceans and lakes. In drier areas, increased evaporation can actually accelerate surface drying, which can lead to droughts (EPA 2009). Overall, according to the IPCC (IPCC 2013b), global mean precipitation is expected to increase under all climate scenarios. However, spatial and seasonal variations 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 2009).

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 (IPCC 2013b) summary of precipitation represents the most thoroughly reviewed, credible means of producing an assessment of this highly uncertain factor. NHTSA expects that the Final Action and alternatives would reduce anticipated changes in precipitation (i.e., in a reference case with no GHG emissions reduction policies) in proportion to the effects of the alternatives on temperature.

The global mean change in precipitation provided by the IPCC for the RCP8.5 (high), RCP6.0 (medium-high), RCP4.5 (medium) and RCP2.6 (low) scenarios (IPCC 2013b) 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 5.4.1-8. The IPCC provides average scaling factors in the year range of 2006 to 2100. NHTSA used the scaling factors for the RCP6.0 scenario (which has a radiative forcing in 2100 of 6 W/m^2, similar to the GCAM Reference scenario's radiative forcing of 7 W/m^2) in this analysis because MAGICC does not directly estimate changes in global mean precipitation.

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 compared to the No Action Alternative, as shown in Table 5.4.1-9 (based on the scaling factor from the RCP6.0 scenario).

Table 5.4.1-8. Rates of Global Mean Precipitation Increase over the 21st Century, per Emissions Scenario

Scenario	Percent per °C
RCP8.5	1.58
RCP6.0	1.68
RCP4.5	1.96
RCP2.6	2.39

Notes:
Source: Figure 12-7 in IPCC 2013b.

Table 5.4.1-9. Global Mean Precipitation (percent Increase) Based on GCAM Reference Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative, Direct and Indirect Impacts[a]

Scenario	2040	2060	2100
Global Mean Precipitation Change (scaling factor, % change in precipitation per °C change in temperature)	1.68		
Global Temperature Above Average 1986–2005 Levels (°C) for the GCAM Reference Scenario by Alternative			
Alt. 1 – No Action	1.287	2.008	3.484
Alt. 2	1.287	2.008	3.483
Alt. 3 – Preferred	1.287	2.006	3.480
Alt. 4	1.287	2.007	3.481
Alt. 5	1.286	2.006	3.480
Reduction in Global Temperature (°C) by Alternative, (Compared to the No Action Alternative)[b]			
Alt. 2	0.000	0.001	0.001
Alt. 3 – Preferred	0.001	0.002	0.004
Alt. 4	0.000	0.001	0.003
Alt. 5	0.001	0.002	0.004
Global Mean Precipitation Increase by Alternative (%)			
Alt. 1 – No Action	2.16%	3.37%	5.85%
Alt. 2	2.16%	3.37%	5.85%
Alt. 3 – Preferred	2.16%	3.37%	5.85%
Alt. 4	2.16%	3.37%	5.85%
Alt. 5	2.16%	3.37%	5.85%
Reduction in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alt. 2	0.00%	0.00%	0.00%
Alt. 3 – Preferred	0.00%	0.00%	0.01%

Scenario	2040	2060	2100
Alt. 4	0.00%	0.00%	0.01%
Alt. 5	0.00%	0.00%	0.01%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.

GCAM = Global Change Assessment Model; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; °C = degrees Celsius.

In addition to changes in mean annual precipitation, climate change is anticipated to affect the intensity of precipitation.[36] Regional variations and changes in the intensity of precipitation cannot be further quantified, 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 RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high) and RCP8.5 (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 multiple AOGCMs produce results regionally consistent in some cases but inconsistent in others.

Table 5.4.1-10 summarizes, in qualitative terms, the regional changes in precipitation from the IPCC Fifth Assessment Report. Quantifying the changes in regional climate under the action alternatives is not possible at this time, but the action alternatives would be expected to reduce the relative precipitation changes in proportion to the reduction in global mean surface temperature.

Table 5.4.1-10. Regional Changes to Precipitation Summarized from the IPCC Fifth Assessment Report

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
Africa	Northern Africa and Northern Sahara	*Very Likely* decreases in mean annual precipitation[b]	
	Eastern Africa	*Likely* increases in mean annual precipitation beginning mid-century[b] *Likely* to increase during short rainy season *Likely* increase in heavy precipitation	
	Central Africa	*Likely* increases in mean annual precipitation beginning mid-century[b]	
	Southern Africa	*Very likely* decreases in mean annual precipitation[b]	
	Western Africa		
Mediterranean and Europe	Northern Europe		*Likely* to decrease
	Central Europe		
	Southern Europe	*Likely* decrease in summer	

[36] 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."

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
	and Mediterranean	precipitation	
Asia	Central Asia	*Very likely* increase in annual precipitation by mid-century[a]	
	Northern Asia	*Very likely* increase in annual precipitation by mid-century[a]	
	Eastern Asia	Precipitation in boreal summer and winter 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	
	West Asia		
	South Asia	*Very likely* increase in annual precipitation by end of century[a]	
	Southeast Asia	*Very likely* increase in annual precipitation by end of century[a]	
North America	Northern regions/Northern North America	*Very likely* increase in precipitation by mid-century[a]	Snow season length and snow depth are *very likely* to decrease
	Southwest		Snow season length and snow depth are *very likely* to decrease
	Northeast USA		Snow season length and snow depth are *very likely* to decrease
	Southern Canada		
	Canada	*Very likely* increase in precipitation by mid-century[a]	Snow season length and snow depth are *very likely* to decrease
	Northernmost part of Canada	*Very likely* increase in precipitation by mid-century[a]	Snow season length and snow depth are *likely* to increase
Central and South America	Central America and the Caribbean		
	Southeastern South America	*Very likely* that precipitation will increase	
	Amazon Region	*Very likely* that precipitation will decrease in the eastern Amazon during the dry season	
	Andes and Western South America	*Very likely* that precipitation will decrease in the Central Chile and the Northern part of this region	
	Northeastern Brazil	*Very likely* that precipitation will decrease during the dry season	
Australia and New Zealand	Southern Australia		
	Southwestern Australia		
	New Zealand	*Likely* to increase in the western regions during winter and spring	

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
Polar Regions	Arctic	*Likely* increase in precipitation	
	Antarctic	*Likely* increase in precipitation	
Small Islands		Rainfall *likely* to increase over certain regions	

Note: Information is omitted from the table where no data was available from AR5.

Regional changes are provided for end-of-century compared to today's baseline, unless otherwise noted. Future modeled change can vary depending on a number of factors such as the concentration pathways used to drive the climate models (e.g., the amount of CO_2 emitted each year around the globe). The following superscripts were used to distinguish the various concentration pathways associated with specific findings:

[a] RCP2.6

[b] RCP8.5

[c] RCP4.5

[d] RCP6.0

[e] SRES A1B

Source: IPCC 2013b.

5.4.1.3.4 Sea-Level Rise

IPCC identifies five 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, (4) loss of land-based ice in Greenland, and (5) contributions from anthropogenic impacts on land water storage (e.g., extraction of ground water) (IPCC 2013b). Ocean circulation, changes in atmospheric pressure, and geological processes can also influence sea-level rise at a regional scale (EPA 2009). The Working Group I contribution to the IPCC Fifth Assessment Report (AR5) (IPCC 2013b) projects the mean sea-level rise for each of the RCP scenarios. As noted in Section 5.3.3.2, NHTSA has used the relationship between the sea-level rise and temperature increases for each of the scenarios from IPCC AR5 to project sea-level rise in this EIS.

IPCC AR5 projects ranges of sea-level rise for each of the RCP scenarios. For 2081 to 2100, sea-level rise is likely to increase 26 to 55 centimeters (10.2 to 21.7 inches) for RCP2.6, 32 to 63 centimeters (12.6 to 24.8 inches) for RCP4.5, 33 to 63 centimeters (13.0 to 24.8 inches) for RCP6.0, and 45 to 82 centimeters (17.7 to 32.3 inches) for RCP8.5 compared to 1986–2005 (IPCC 2013b). Sea-level rise projections in AR5 are substantially higher than those in the Fourth Assessment Report (AR4) because they include significant contributions of melting from large ice sheets (in particular, Greenland and Antarctica) and mountain glaciers in AR5 compared to AR4. Further, the contribution from anthropogenic impacts on land water, which were not included in AR4, also adds to the overall increase in projected sea-level rise (IPCC 2013b). However, IPCC results for sea-level projections are still lower than those modeled by some other studies, which were based largely on semi-empirical relationships (USACE 2014). NOAA notes that there is high confidence that the global mean sea level will rise at least 20 centimeters (8 inches) and no more than 200 centimeters (78 inches) by 2100 (GCRP 2014 citing Parris et al. 2012). *See* Sections 5.1.5 and 5.3.3.2 for more information on sea-level rise.

Table 5.4.1-6 lists the impacts of the action alternatives on sea-level rise under the GCAM Reference scenario. This analysis shows sea-level rise in 2100 ranging from 76.28 centimeters (30.03 inches) under the No Action Alternative to 76.19 centimeters (30.00 inches) under Alternative 5. This represents a maximum reduction of 0.09 centimeter (0.03 inch) by 2100 under Alternative 5 compared to the No Action Alternative.

5.4.1.3.5 Climate Sensitivity Variations

Using the methodology described in Section 5.3.3.5, NHTSA examined the sensitivity of projected climate impacts on 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 GCAM Reference scenario.

Table 5.4.1-11 lists the results from the sensitivity analysis, which included climate sensitivities of 1.5°C, 2.0°C, 2.5°C, 3.0°C, 4.5°C, and 6.0°C (2.7°F, 3.6°F, 4.5°F, 5.4°F, 8.1°F, and 10.8°F) for a doubling of CO_2 compared to pre-industrial atmospheric concentrations (280 ppm CO_2) (*see* Section 5.3.3.5).

Table 5.4.1-11. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level Rise for Varying Climate Sensitivities for Selected Alternatives, Direct and Indirect Impacts[a]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[b]
		2040	2060	2100	2040	2060	2100	2100
Alt. 1 – No Action	1.5	469.61	546.10	737.48	0.741	1.128	1.890	41.05
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	52.74
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	64.52
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	76.28
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	110.93
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	144.70
Alt. 3 – Preferred	1.5	469.47	545.70	736.60	0.740	1.127	1.888	41.01
	2.0	472.95	552.69	754.58	0.941	1.444	2.448	52.70
	2.5	476.08	559.12	771.76	1.122	1.737	2.978	64.46
	3.0	478.90	565.03	788.15	1.287	2.006	3.480	76.21
	4.5	485.86	580.21	833.26	1.698	2.705	4.863	110.82
	6.0	491.20	592.45	873.80	2.019	3.277	6.164	144.54
Reduction Under Preferred Alternative Compared to No Action Alternative								
	1.5	0.14	0.40	0.88	0.000	0.001	0.002	0.03
	2.0	0.14	0.40	0.91	0.000	0.001	0.003	0.05
	2.5	0.14	0.40	0.93	0.000	0.002	0.003	0.06
	3.0	0.14	0.41	0.95	0.001	0.002	0.004	0.07
	4.5	0.14	0.42	1.02	0.001	0.002	0.005	0.11
	6.0	0.14	0.42	1.09	0.001	0.003	0.007	0.16

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.

CO_2 = carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters.

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 5.4.1-11 shows, 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.

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 Table 5.4.1-11. 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. The reduction in 2100 global mean surface temperature from the No Action Alternative to the Preferred Alternative ranges from 0.002°C (0.004°F) for the 1.5°C (2.7°F) climate sensitivity to 0.007°C (0.013°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 Table 5.4.1-11. Scenarios with lower climate sensitivities show generally smaller increases in sea-level rise; at the same time, 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, sea-level rise is lower under the Preferred Alternative than under the No Action Alternative. The range in reduction of sea-level rise under the Preferred Alternative compared to the No Action Alternative is 0.03 to 0.16 centimeter (0.013 to 0.061 inch), 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 this rulemaking together with those of other past, present, and reasonably foreseeable future actions.

5.4.2.1 Greenhouse Gas Emissions

NHTSA estimated the emissions resulting from the Final Action and alternatives using the methodologies described in Section 5.3. GHG emissions from MY 2051–2100 HD vehicles were then scaled using GCAM assumptions regarding the projected growth of U.S. transportation fuel consumption (*see* Section 5.3.1). Cumulative emissions reductions under each action alternative increase with the increasing stringency of the alternatives, with Alternative 2 having the smallest cumulative emissions reductions and Alternative 5 having the largest. Table 5.4.2-1 and Figure 5.4.2-1 show total CO_2 emissions and emissions reductions projected to result from new U.S. HD vehicles from 2018 to 2100 under each action alternative. Between 2018 and 2100, projections of cumulative emissions reductions due to this rulemaking and other reasonably foreseeable future actions range from 5,000 to 14,200 $MMTCO_2$. Compared to cumulative global emissions of 4,154,831 $MMTCO_2$ 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 0.1 to 0.3 percent from their projected levels under the No Action Alternative.

Table 5.4.2-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from all HD Vehicles 2018 to 2100 by Alternative, Cumulative Impacts[a]

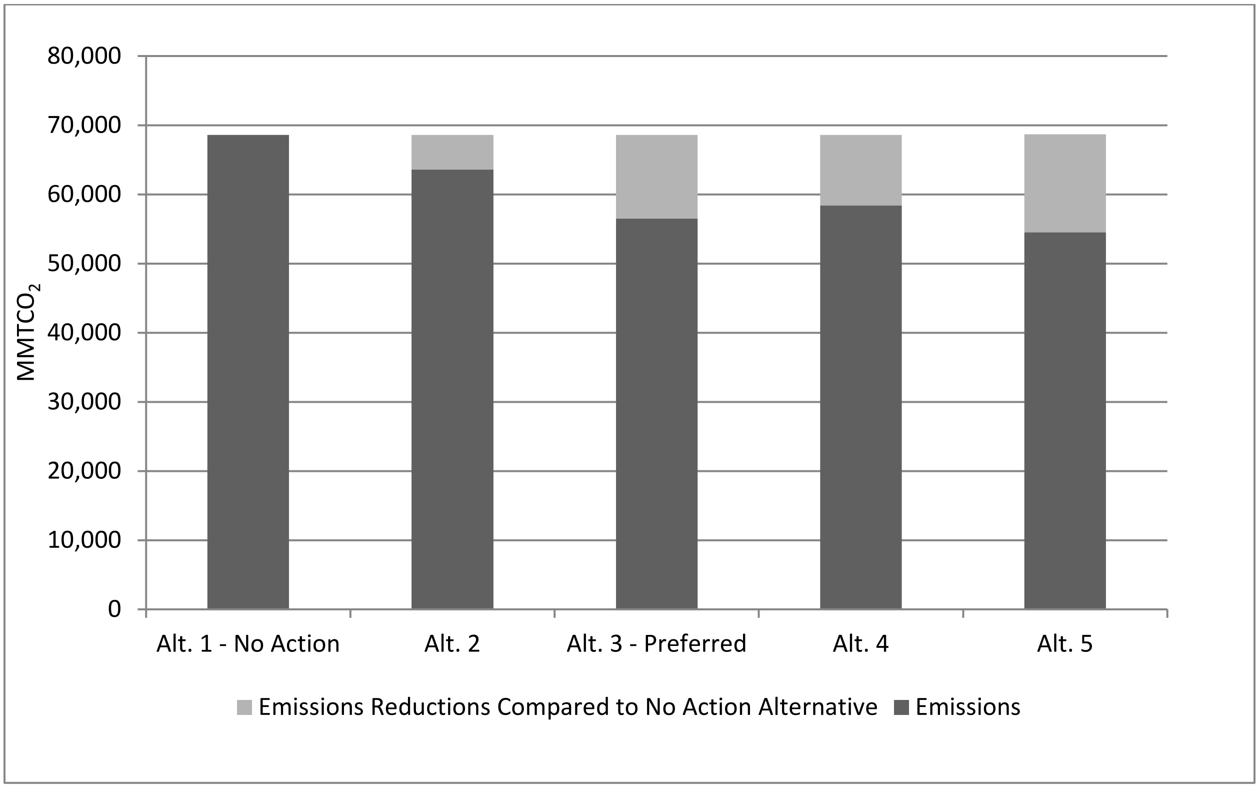
Alternative	Total Emissions	Emissions Reductions Compared to No Action Alternative	Percent Emissions Reductions Compared to No Action Alternative Emissions
Alt. 1 – No Action	68,600		
Alt. 2	63,600	5,000	7%
Alt. 3 – Preferred	56,500	12,100	18%
Alt. 4	58,400	10,200	15%
Alt. 5	54,500	14,200	21%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact differences between the values.

CO_2 = carbon dioxide; $MMTCO_2$ = million metric tons of carbon dioxide; HD = heavy duty.

Figure 5.4.2-1. CO_2 Emissions and Emissions Reductions ($MMTCO_2$) from All HD Vehicles 2018 to 2100 by Alternative, Cumulative Impacts

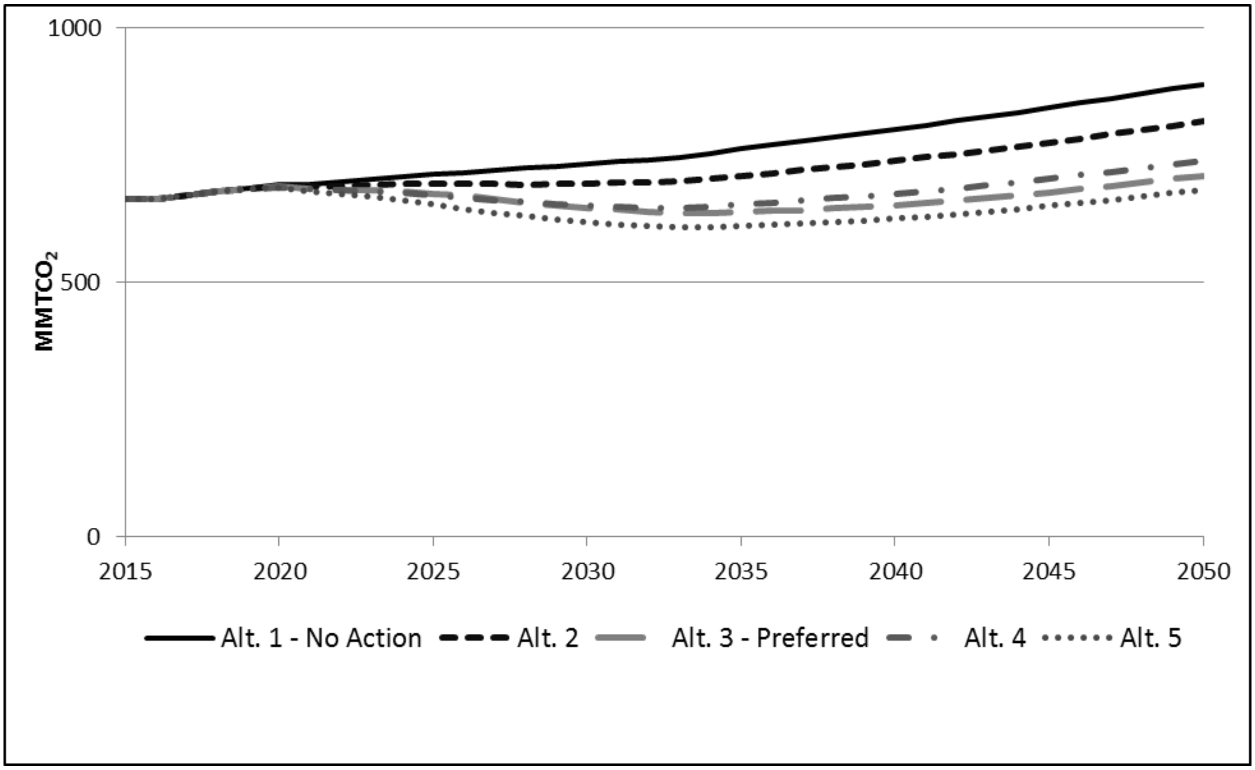


CO_2 = carbon dioxide; $MMTCO_2$ = million metric tons of carbon dioxide; HD = heavy duty.

To illustrate the relative impact of these reductions, it can be helpful to consider the magnitude of U.S. emissions from HD vehicles and to compare them to total U.S. emissions from all sources. HD vehicles in the United States currently account for approximately 7.6 percent of U.S. CO_2 emissions. With the action alternatives reducing U.S. HD vehicle CO_2 emissions by 7 to 21 percent over the period 2018–2100 under the cumulative impacts analysis presented in this chapter, this rulemaking would contribute to reducing total U.S. CO_2 emissions compared to the No Action Alternative. Compared to total U.S. CO_2 emissions by the end of the century projected by the GCAM6.0 scenario of 4,402 $MMTCO_2$ (Clarke et al.

2007), the action alternatives and reasonably foreseeable future increases in HD vehicle fuel efficiency would reduce total U.S. CO_2 emissions by a range of 1.5 to 4.3 percent in the year 2100.[37] Figure 5.4.2-2 shows projected annual emissions from U.S. HD vehicles under the alternatives taken together with reasonably foreseeable future actions.

Figure 5.4.2-2. Projected Annual CO_2 Emissions ($MMTCO_2$) from All HD Vehicles by Alternative, Cumulative Impacts



CO_2 = carbon dioxide; $MMTCO_2$ = million metric tons of carbon dioxide; HD = heavy duty.

Table 5.4.2-2 shows projected emissions of CO_2, CH_4, and N_2O to 2100 under the alternatives. CO_2 emissions account for almost all—97 percent—of GWP-weighted emissions. As shown in this table, CO_2 emissions from the HD vehicle fleet in the United States are projected to increase substantially from their levels in 2018 under the No Action Alternative, which assumes increases in both the number of HD vehicles and in VMT per vehicle. This table also shows that each action alternative would reduce total HD 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 2050, due to decreased fuel consumption as the fleet turns over.

[37] 2095 is the last year emissions data are available from GCAMReference.

Table 5.4.2-2. Emissions of Greenhouse Gases ($MMTCO_2e$ per year) from All HD Vehicles by Alternative, Cumulative Impacts

GHG and Year	Alt. 1 – No Action	Alt. 2	Alt. 3 – Preferred	Alt. 4	Alt. 5
Carbon Dioxide (CO_2)					
2020	692	690	688	688	687
2040	801	739	652	674	625
2060	885	812	707	736	679
2080	879	807	702	731	675
2100	817	750	653	680	627
Methane (CH_4)					
2020	18.96	18.88	18.84	18.83	18.81
2040	21.89	20.25	18.03	18.55	17.32
2060	24.10	22.18	19.50	20.20	18.76
2080	23.93	22.02	19.36	20.06	18.63
2100	22.25	20.48	18.01	18.66	17.33
Nitrous oxide (N_2O)					
2020	2.31	2.29	2.29	2.29	2.28
2040	2.34	2.22	2.09	2.11	2.04
2060	2.54	2.40	2.24	2.28	2.20
2080	2.52	2.39	2.23	2.26	2.18
2100	2.34	2.22	2.07	2.10	2.03
Total (all GHGs)					
2020	713	711	709	709	708
2040	826	762	672	695	645
2060	912	837	729	759	700
2080	905	831	723	754	695
2100	842	773	673	701	647

Notes:
$MMTCO_2e$ = million metric tons carbon dioxide equivalent; HD = heavy duty; GHG = greenhouse gas.

For the cumulative impacts analysis, under each alternative analyzed, growth in the number of HD vehicles in use throughout the United States, combined with assumed increases in their average use, is projected to result in growth of HD vehicle travel. This growth in VMT more than offsets the effect of improvements in HD vehicle fuel efficiency in 2100 under Alternative 2, resulting in projected increases above present levels in total fuel consumption by HD 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 HD vehicles. Under Alternatives 3, 4, and 5, increases in HD vehicle fuel efficiency are expected to result in fuel consumption and CO_2 emissions levels in 2100 that are lower than 2020 projected annual CO_2 emissions levels.

Emissions of CO_2 (the primary gas that drives climate effects) from the U.S. HD vehicle fleet represented approximately 1.1 percent of total global emissions of CO_2 in 2012 (EPA 2016c, WRI 2016).[38] Although substantial, this source is still a small percentage of global emissions. The proportion of global CO_2

[38] Includes land-use change and forestry and excludes international bunker fuels.

emissions attributable to HD vehicles is expected to decline in the future, due primarily to rapid growth of emissions from developing economies (which is due, in part, to growth in global transportation sector emissions).

One global climate stabilization goal that has been gaining recognition is the idea of a global carbon "budget," which is an estimate for the total amount of anthropogenic CO_2 that can be emitted to have a certain chance of limiting the global average temperature increase to below 2°C relative to pre-industrial levels. The IPCC estimates that if cumulative global emissions from 1870 onwards are limited to approximately 1,000 Gigatonnes (Gt) C (3,670 Gt CO_2), then the probability of limiting the temperature increase to below 2°C is greater than 66 percent. As of 2011, approximately 51 percent, or 515 Gt C (1,890 Gt CO_2), of this budget had already been emitted, leaving a remaining budget of 485 Gt C (1,780 Gt CO_2) (IPCC 2013b).

The emissions reductions necessary to keep global emissions within this carbon budget could not be achieved solely with drastic reductions in emissions from the U.S. HD vehicle fleet but would also require drastic reductions in all U.S. sectors and from the rest of the developed and developing world. In addition, achieving GHG reductions from the HD vehicle fleet to the same degree that emissions reductions will be needed globally to avoid using all of the carbon budget would require substantial increases in technology innovation and adoption compared to today's levels and would require an economy and vehicle fleet that has largely moved away from the use of fossil fuels, which is not currently technologically feasible or economically practicable.

5.4.2.2 Social Cost of Greenhouse Gases

Consistent with the methodology described in Section 5.4.1.2, Table 5.4.2-3 lists the cumulative impacts of the action alternatives in terms of reduced monetized damages for CO_2, CH_4 and N_2O. Consistent with the table in Section 5.4.1.2 (Table 5.4.1-4), 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 from CO_2, CH_4, and N_2O Emissions Reductions Due to Phase 2 HD Standards for Each Regulatory Alternative, Cumulative Impacts[a]

Alternative	5% Discount Rate	3% Discount Rate	2.5% Discount Rate	3% Discount Rate (95th Percentile Damages)
Alt. 2	$9,918	$45,651	$72,532	$138,744
Alt. 3 – Preferred	$23,041	$106,539	$169,433	$324,005
Alt. 4	$20,461	$94,105	$149,494	$285,992
Alt. 5	$28,494	$130,998	$208,088	$398,119

Notes:

[a] Net present value in 2015, in millions of 2013 dollars. Includes emissions reductions that occur between 2017 and 2050 as a result of Phase 2 HD standards.

CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; HD = heavy duty.

5.4.2.3 Cumulative Impacts on Climate Change Indicators

Using the methodology described in Chapter 2 and Section 5.3.3.3.2, 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 this rulemaking, 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.[39] 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-lasting.

MAGICC6 is a simple climate model and well calibrated to the mean of the multi-model ensemble results for four of the most commonly used emissions scenarios (i.e., RCP 2.6 [low], RCP 4.5 [medium], RCP 6.0 [medium-high], and RCP8.5 [high]) from the IPCC RCP series.

The GCAM6.0 scenario, described in Section 5.3.3.3, was used to represent the No Action Alternative in the MAGICC runs for the cumulative impacts section of this EIS. Table 5.4.2-4 and Figure 5.4.2-3 through Figure 5.4.2-6 show the mid-range results of MAGICC model simulations for the No Action Alternative and the four action alternatives for CO_2 concentrations and increase in global mean surface temperature in 2040, 2060, and 2100. As Figure 5.4.2-3 and Figure 5.4.2-4 show, the action alternatives produce a reduction in the increase in projected CO_2 concentration and 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, Figure 5.4.2-3 and Figure 5.4.2-4, the band of estimated CO_2 concentrations as of 2100 is fairly narrow, from a range of 686.1 ppm under Alternative 5 to 687.3 ppm under the No Action Alternative. For 2040 and 2060, the corresponding ranges are similar. 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 by Alternative, Cumulative Impacts[a]

Alternative	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea-Level Rise (cm)[b]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100
Alt. 1 – No Action	472.6	546.0	687.3	1.216	1.810	2.838	22.16	35.15	70.22
Alt. 2	472.5	545.8	686.9	1.215	1.810	2.836	22.16	35.14	70.19
Alt. 3 – Preferred	472.4	545.6	686.3	1.215	1.808	2.834	22.16	35.13	70.14
Alt. 4	472.4	545.6	686.4	1.215	1.809	2.834	22.16	35.14	70.15
Alt. 5	472.4	545.5	686.1	1.215	1.808	2.833	22.16	35.13	70.12
Reductions Under Alternatives									
Alt. 2	0.1	0.2	0.4	0.000	0.001	0.002	0.00	0.01	0.04
Alt. 3 – Preferred	0.2	0.4	1.0	0.001	0.002	0.004	0.00	0.02	0.09
Alt. 4	0.1	0.4	0.9	0.001	0.002	0.004	0.00	0.01	0.07
Alt. 5	0.2	0.5	1.2	0.001	0.002	0.005	0.00	0.02	0.10

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.

CO_2 = carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters.

[39] 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).

5.4.2.3.1 Atmospheric CO_2 Concentrations

As Figure 5.4.2-3 and Figure 5.4.2-4 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 Figure 5.4.2-4, the reduction in CO_2 concentrations by 2100 under Alternative 5 is more than twice that of Alternative 2.

Figure 5.4.2-3. Atmospheric CO_2 Concentrations by Alternative, Cumulative Impacts

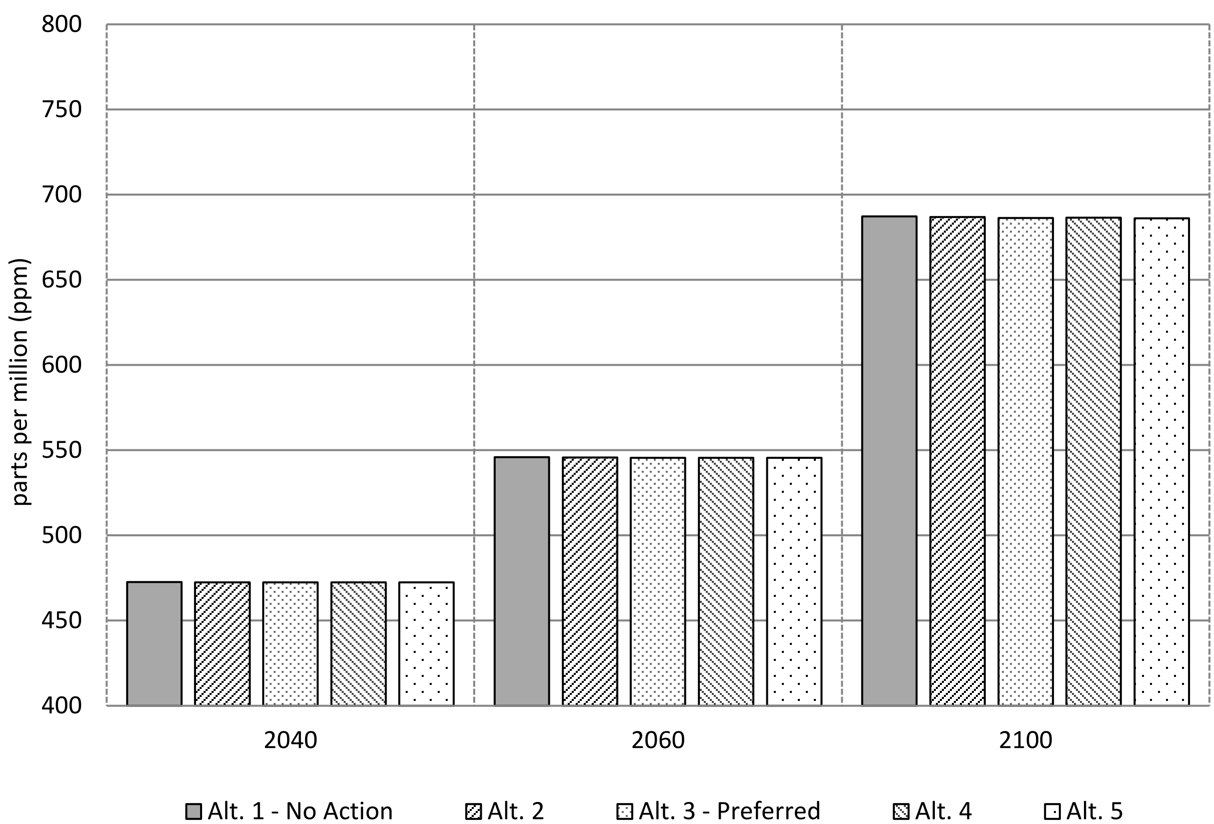
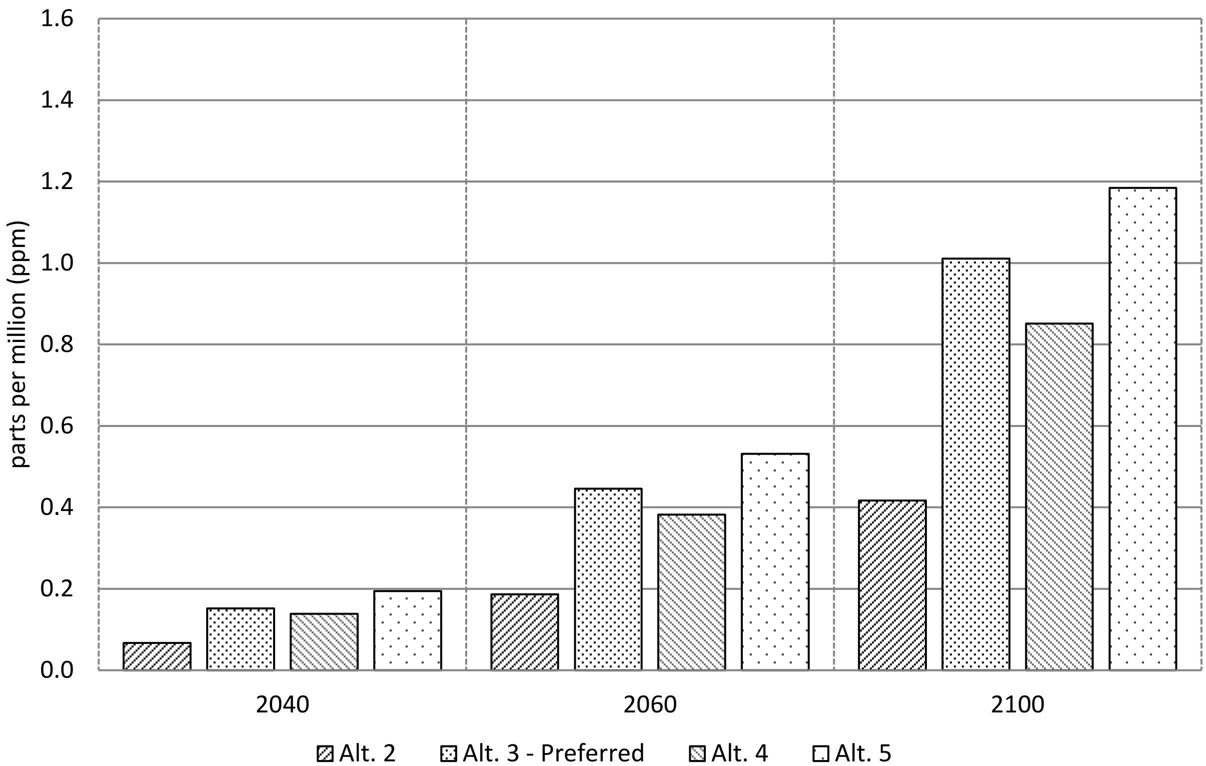


Figure 5.4.2-4. Reduction in Atmospheric CO_2 Concentrations Compared to the No Action Alternative, Cumulative Impacts



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, assuming an emissions scenario that considers a moderate global effort to reduce GHG emissions, the cumulative global mean surface temperature is projected to increase by 1.22°C (2.19°F) by 2040, 1.81°C (3.26°F) by 2060, and 2.84°C (5.11°F) by 2100.[40] The differences among alternatives are small. For example, in 2100 the reduction in temperature increase under the action alternatives compared to the No Action Alternative ranges from approximately 0.002°C (0.003°F) under Alternative 2 to 0.005°C (0.009°F) under Alternative 5. Quantifying the changes to regional climate from this rulemaking 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 regional temperatures roughly in proportion to the reduction in global mean surface temperature. Regional changes to warming and seasonal temperatures as described in the IPCC Fifth Assessment Report are summarized in Table 5.4.2-6.

[40] 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 5.4.2-5. Global Mean Surface Temperature Increase by Alternative, Cumulative Impacts

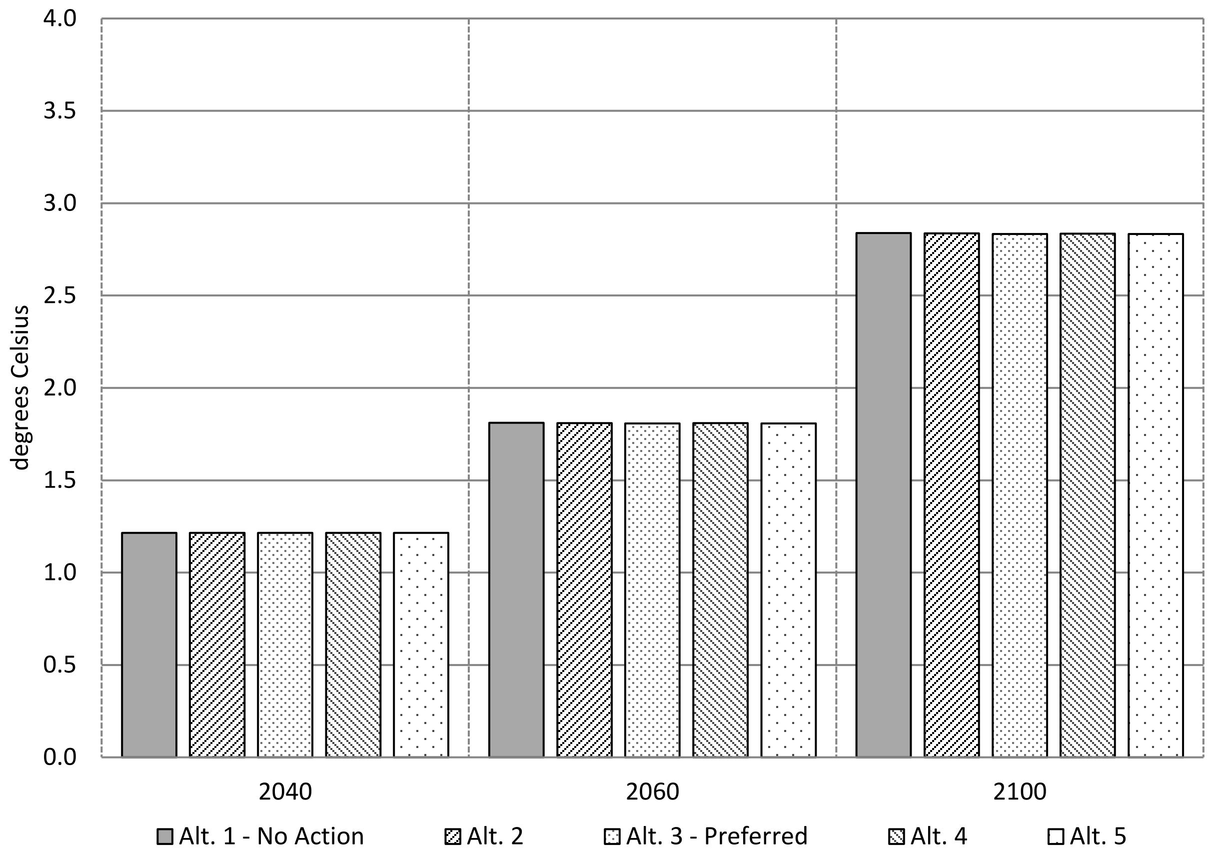
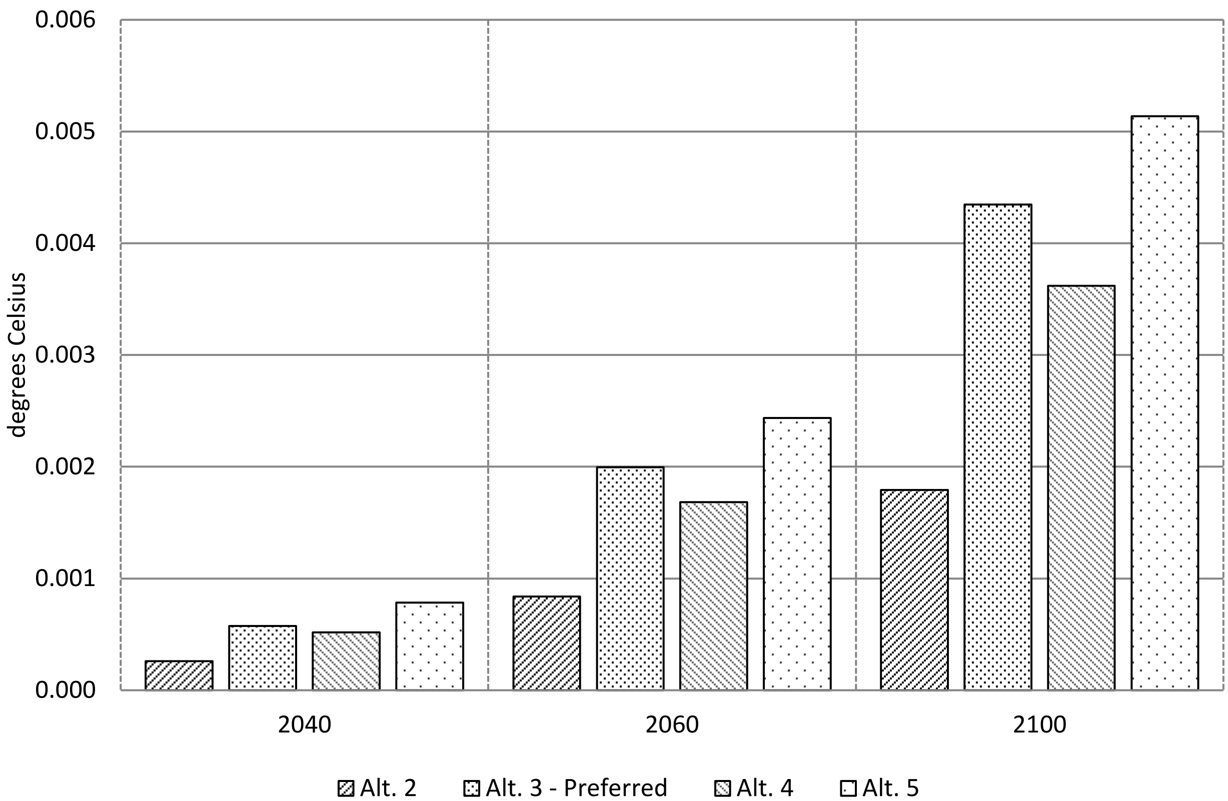


Figure 5.4.2-6. Reduction in Global Mean Surface Temperature Compared to the No Action Alternative, Cumulative Impacts



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 compared to the No Action Alternative, they also would reduce predicted increases in precipitation slightly, as shown in Table 5.4.2-5.

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 with very large changes in emissions, such as the RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high) and RCP8.5 (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 (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, by Alternative, Cumulative Impacts[a]

Scenario	2040	2060	2100
Global Mean Precipitation Change (scaling factor, % change in precipitation per °C change in temperature)		1.68	
Global Temperature Above Average 1986–2005 Levels (°C) for the GCAM6.0 Scenario by Alternative			
Alt. 1 – No Action	1.216	1.810	2.838
Alt. 2	1.215	1.810	2.836
Alt. 3 – Preferred	1.215	1.808	2.834
Alt. 4	1.215	1.809	2.834
Alt. 5	1.215	1.808	2.833
Reduction in Global Temperature (°C) by Alternative, (Compared to the No Action Alternative)[b]			
Alt. 2	0.000	0.001	0.002
Alt. 3 – Preferred	0.001	0.002	0.004
Alt. 4	0.001	0.002	0.004
Alt. 5	0.001	0.002	0.005
Global Mean Precipitation Increase by Alternative (%)			
Alt. 1 – No Action	2.04%	3.04%	4.77%
Alt. 2	2.04%	3.04%	4.76%
Alt. 3 – Preferred	2.04%	3.04%	4.76%
Alt. 4	2.04%	3.04%	4.76%
Alt. 5	2.04%	3.04%	4.76%
Reduction in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alt. 2	0.00%	0.00%	0.00%
Alt. 3 – Preferred	0.00%	0.00%	0.01%
Alt. 4	0.00%	0.00%	0.01%
Alt. 5	0.00%	0.00%	0.01%

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the reductions might not reflect the exact difference of the values in all cases.

[b] Precipitation changes reported as 0.000 are more than zero but less than 0.001.

GCAM = Global Change Assessment Model; MAGICC = Model for the Assessment of Greenhouse-gas Induced Climate Change; °C = degrees Celsius.

Quantifying the changes in regional climate from the action alternatives is not possible at this point, but the action alternatives would reduce regional changes in precipitation roughly in proportion to the reduction in global mean precipitation. Regional changes to precipitation as described by the IPCC Fourth Assessment Report are summarized in Table 5.4.1-10 in Section 5.4.1.3.3.

5.4.2.3.4 Sea-Level Rise

The components of sea-level rise, treatment of these components, and recent scientific assessments are discussed in Section 5.4.1.3.4. Table 5.4.2-4 presents the cumulative impact on sea-level rise from the scenarios and show sea-level rise in 2100 ranging from 70.22 centimeters (27.65 inches) under the No Action Alternative to 70.12 centimeters (27.61 inches) under Alternative 5, for a maximum reduction of 0.10 centimeter (0.04 inch) by 2100.

5.4.2.3.5 Climate Sensitivity Variations

NHTSA examined the sensitivity of climate impacts 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. NHTSA performed the sensitivity analysis around two of the alternatives—the No Action Alternative and the Preferred Alternative–because the agency believes this is sufficient to assess the effect of various climate sensitivities on the results. Table 5.4.2-6 presents the results of the sensitivity analysis for cumulative impacts.

Table 5.4.2-6. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-Level Rise for RCP 4.5[a] for Selected Alternatives, Cumulative Impacts[b]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Alt. 1 – No Action	1.5	454.05	494.89	510.15	0.619	0.859	1.040	31.58
	2.0	457.30	500.90	521.85	0.793	1.114	1.389	40.80
	2.5	460.23	506.45	533.11	0.952	1.352	1.729	50.33
	3.0	462.88	511.57	543.93	1.097	1.573	2.059	60.04
	4.5	469.44	524.72	573.71	1.464	2.152	2.978	89.27
	6.0	474.49	535.31	599.95	1.752	2.627	3.797	117.62
Alt. 3 – Preferred	1.5	453.90	494.46	509.30	0.618	0.857	1.037	31.54
	2.0	457.15	500.47	520.97	0.792	1.112	1.385	40.74
	2.5	460.08	506.02	532.21	0.951	1.350	1.725	50.26
	3.0	462.73	511.13	543.01	1.096	1.571	2.054	59.95
	4.5	469.29	524.27	572.73	1.463	2.149	2.971	89.12
	6.0	474.33	534.86	598.91	1.751	2.624	3.789	117.43
Reduction Under Preferred Alternative Compared to the No Action Alternative								
	1.5	0.15	0.43	0.85	0.000	0.001	0.003	0.04
	2.0	0.15	0.43	0.88	0.000	0.002	0.004	0.06
	2.5	0.15	0.43	0.90	0.001	0.002	0.004	0.08
	3.0	0.15	0.44	0.93	0.001	0.002	0.005	0.09
	4.5	0.15	0.45	0.99	0.001	0.003	0.006	0.14
	6.0	0.15	0.45	1.04	0.001	0.003	0.008	0.19

Notes:

[a] Sea-level rise results are based on the regression analysis described in Section 5.3.3.

[b] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[c] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.

CO_2 = carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters; RCP = Representative Concentration Pathways.

The use of alternative global emissions scenarios can influence the results in several ways. Emissions reductions under higher emissions scenarios can lead to larger reductions in CO_2 concentrations in later years. Under higher emissions scenarios, anthropogenic emissions levels exceed global emissions sinks (e.g., plants, oceans, and soils) by a greater extent. As a result, emissions reductions under higher emissions scenarios are avoiding more of the anthropogenic emissions that are otherwise expected to stay in the atmosphere (are not removed by sinks) and contribute to higher CO_2 concentrations. 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 projected warming but also indirectly affect projected 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 through Table 5.4.2-8, the sensitivity of simulated CO_2 emissions in 2040, 2060, and 2100 to assumptions of global emissions and climate sensitivity is low; stated simply, the incremental changes in CO_2 concentration (i.e., the difference between the Preferred Alternative and the No Action Alternative) are insensitive to different assumptions on 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 on CO_2 concentration in the global emissions scenario with the highest CO_2 emissions (GCAM Reference 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 0.85 to 1.17 ppm across all three global emissions scenarios. The Preferred Alternative using the GCAM6.0 scenario and a 3.0°C (5.4°F) climate sensitivity has an impact of a 1.01 ppm reduction compared to the No Action Alternative in 2100.

Table 5.4.2-7. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-Level Rise for GCAM 6.0[a] for Selected Alternatives, Cumulative Impacts[b]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea-Level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Alt. 1 – No Action	1.5	463.33	527.73	643.45	0.694	1.005	1.506	36.94
	2.0	466.74	534.33	658.72	0.885	1.294	1.971	47.83
	2.5	469.80	540.41	673.33	1.058	1.562	2.415	58.97
	3.0	472.56	546.00	687.29	1.216	1.810	2.838	70.22
	4.5	479.39	560.37	725.55	1.611	2.456	3.998	103.79
	6.0	484.62	571.96	759.36	1.920	2.984	5.037	136.36
Alt. 3 – Preferred	1.5	463.18	527.29	642.51	0.694	1.003	1.503	36.90
	2.0	466.58	533.89	657.76	0.884	1.293	1.968	47.77
	2.5	469.65	539.96	672.34	1.058	1.560	2.411	58.90
	3.0	472.41	545.56	686.28	1.215	1.808	2.834	70.14
	4.5	479.23	559.92	724.47	1.611	2.453	3.992	103.66
	6.0	484.47	571.50	758.22	1.920	2.981	5.030	136.18
Reduction Under Preferred Alternative Compared to the No Action Alternative								
	1.5	0.15	0.43	0.94	0.000	0.001	0.003	0.04
	2.0	0.15	0.44	0.96	0.000	0.002	0.003	0.06
	2.5	0.15	0.44	0.99	0.001	0.002	0.004	0.07
	3.0	0.15	0.45	1.01	0.001	0.002	0.004	0.09

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea-Level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
	4.5	0.15	0.45	1.07	0.001	0.003	0.006	0.14
	6.0	0.15	0.46	1.14	0.001	0.003	0.007	0.18

Notes:

[a] Sea-level rise results are based on the regression analysis described in section 5.3.3 Methods for Estimating Climate Effects using GCAM 6.0.

[b] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[c] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986–2005.

CO_2 = carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters; GCAM = Global Change Assessment Model.

Table 5.4.2-8. CO_2 Concentrations, Global Mean Surface Temperature Increases, and Sea-level rise for GCAM Reference[a] for Selected Alternatives, Cumulative Impacts[b]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[c]
		2040	2060	2100	2040	2060	2100	2100
Alt. 1 – No Action	1.5	469.61	546.10	737.48	0.741	1.128	1.890	41.05
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	52.74
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	64.52
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	76.28
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	110.93
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	144.70
Alt. 3 – Preferred	1.5	469.46	545.66	736.50	0.740	1.127	1.888	41.01
	2.0	472.94	552.65	754.48	0.941	1.444	2.448	52.69
	2.5	476.07	559.07	771.66	1.122	1.736	2.978	64.46
	3.0	478.88	564.99	788.05	1.286	2.006	3.480	76.20
	4.5	485.84	580.17	833.16	1.698	2.704	4.863	110.81
	6.0	491.19	592.41	873.72	2.019	3.276	6.164	144.53
Reduction Under Preferred Alternative Compared to the No Action Alternative								
	1.5	0.15	0.44	0.98	0.000	0.001	0.002	0.04
	2.0	0.15	0.44	1.01	0.000	0.002	0.003	0.05
	2.5	0.15	0.45	1.03	0.001	0.002	0.004	0.06
	3.0	0.15	0.45	1.06	0.001	0.002	0.004	0.08
	4.5	0.15	0.46	1.12	0.001	0.002	0.006	0.12
	6.0	0.15	0.47	1.17	0.001	0.003	0.008	0.17

Notes:

[a] Sea-level rise results are based on the regression analysis described in section 5.3.3 Methods for Estimating Climate Effects using a hybrid relation based on RCP 6.0 and RCP 8.5.

[b] The numbers in this table have been rounded for presentation purposes. As a result, the reductions do not reflect the exact difference of the values.

[c] The values for global mean surface temperature and sea-level rise are relative to the average of the years 1986-2005.

CO_2 = carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters; GCAM = Global Change Assessment Model.

The sensitivity of the simulated global mean surface temperatures for 2040, 2060, and 2100 varies over the simulation 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 larger due to climate sensitivity and change in emissions. The impact on global mean surface temperature due to assumptions concerning global emissions of GHGs is also important. Under the Preferred Alternative, the scenario with the highest global emissions of GHGs, the GCAM Reference scenario, has a lower reduction in global mean surface temperature than the scenario with lowest global emissions, RCP4.5. This is in large part due to the non-linear 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 through Table 5.4.2-8. 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 alone would not prevent climate change. Instead, they would result in reductions in the anticipated increases of global CO_2 concentrations and associated impacts, including changes in temperature, precipitation, and sea level that are otherwise projected to occur under the No Action Alternative.

By limiting increases in CO_2 concentrations, the action alternatives would also contribute to reducing the impact of climate change across resources that would otherwise occur under the No Action Alternative. Similarly, to the extent the action alternatives would result in reductions in projected increases in global CO_2 concentrations, this rulemaking would contribute to reducing the risk of crossing atmospheric CO_2 concentration thresholds that trigger abrupt changes in Earth's systems—thresholds known as "tipping points" (*see* Section 5.5.2.10 for what that risk would otherwise be under the No Action Alternative). Delaying mitigation in the short term will require more stringent reductions in the future to limit climate change impacts.

NHTSA's assumption is that reductions in climate effects relating to temperature, precipitation, and sea-level rise would reduce 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.[41] Consequently, the discussion of resource impacts in this section does not distinguish among the alternatives; rather it provides a qualitative review of projected impacts (where the potential benefits of reducing GHG emissions would result in reducing these potential impacts). Nonetheless, it is clear that these resources are likely to be beneficially affected to some degree by the reduced climate change impacts expected to result from the action alternatives.

This section also briefly describes ongoing adaptation efforts for various resource areas. While mitigation efforts are required to lower the overall risk of triggering large or accelerating transitions to significantly different physical states within Earth's systems, efforts to adapt to climate change are also necessary to increase the resilience of human and natural systems to the adverse risks of climate change. As a measure of the importance of current and potential climate change impacts, the Obama Administration has identified adaptation as a critical need through Executive Order 13514. This Order requires federal agencies to evaluate agency climate change risks and vulnerabilities to manage both the short- and long-term effects of climate change on the agency's mission, programs, and operations. Pursuant to this Order, CEQ issued a set of Implementing Instructions for Federal Agency Adaptation Planning that informed agencies how to integrate climate change adaptation into their planning, operations, policies, and programs (CEQ 2012).

The health, societal, and environmental impacts discussion is divided into two parts: Section 5.5.2 discusses the sector-specific impacts of climate change, while Section 5.5.3 discusses the region-specific impacts of climate change. Section 5.5.2 further discusses ongoing adaptation efforts for various resource areas.

5.5.2 Sectoral Impacts of Climate Change

This section is divided into discussions of sector-specific impacts of climate change. Specifically, Sections 5.5.2.1 through 5.5.2.9 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).
- Ocean systems, coastal 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).

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[41] This section does not compare the projected reductions in global climate effects in Section 5.4 to the national-, regional-, or local-scale reductions in climate effects presented in Section 5.5. The projected reductions in global climate effects do not translate to identical projected reductions at the national, regional, or local scale. In addition, the projected reductions in global climate effects for each of the alternatives are too small to incorporate into a regional/local-scale analysis, which would likely introduce uncertainties at the same magnitude or more than the projected change itself (i.e., the projected change would be within the noise of the model). However, it is understood that climate change is occurring due to the emissions from a collection of sources, and that mitigation across these sources is necessary to curtail additional warming. 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 and directionally consistent, and will contribute to reducing the risks associated with climate change from what they would otherwise be under the No Action Alternative. While NHTSA does quantify the reductions in monetized damages attributable to each action alternative (in the SCC 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.

- Food, fiber, and forest products (the environmental vulnerabilities of farming, forestry, and fisheries to climate change).
- Urban areas (how climate change might affect human institutions and systems focusing on urban communities, including industrial and service sectors; transportation systems; energy production; and financial, cultural, and social institutions).
- Rural areas (how climate change might affect human institutions and systems, focusing on rural communities).
- Human health (how a changing climate might affect human mortality and morbidity).
- Human security (how climate change could affect livelihoods, cultures, migration and mobility, armed conflict, and state integrity and geopolitical rivalry).
- Stratospheric ozone (how climate change might affect ozone concentrations in the stratosphere).

Following these sections, Section 5.5.2.10 summarizes tipping points, abrupt climate change, and potential thresholds; it is cross- cutting because it addresses some of the resources in Sections 5.5.2.1 through 5.5.2.9.

Sections 5.5.2.1 through 5.5.2.9 first summarize findings related to the consequences of observed and projected climate change in the United States and globally on each resource, drawing largely from recent reports including the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC 2013a, 2013b, 2014a, 2014b) and the U.S. Global Climate Research Program (GCRP) National Climate Assessment (NCA) Report (GCRP 2014). The sections conclude with reviews of the potential to adapt to climate change and the extent to which adaptation could reduce climate change risks. Because adaptation measures will become increasingly expensive in the face of large magnitude climate changes, and there are limits to systems' abilities to adapt, adaptation cannot be considered a substitute for mitigation actions designed to limit climate change impacts.

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 and the GCRP, primary sources for much of the information in this section.

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. This is primarily applied for key IPCC findings where the IPCC has defined the associated uncertainty with the finding (other sources generally do not provide enough information or expert consensus to elicit uncertainty rankings).

In addition to the recent seminal reports from the IPCC and GCRP, additional reports from the GCRP and such agencies as the National Research Council have been included. 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. In addition, as the state of the science continues to evolve since the release date of these reports, the findings from these reports have been supplemented with recent (post 2013) peer-reviewed information. Peer-reviewed information prior to 2013 is included for additional findings that may support or supplement key findings presented by the seminal and panel reports.

5.5.2.1 Freshwater Resources

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. Over 70 percent of the surface of the Earth is covered by water, but only 2.5 percent is freshwater. Respectively, freshwater contributions include permanent snow cover in the Antarctic, the Arctic, and mountainous regions (68.7 percent); groundwater (29.9 percent); and freshwater in lakes, reservoirs, and river systems (0.26 percent) (UNESCO 2006).

Other important non-climate related drivers of change that impact the quantity, quality, availability, and use of freshwater—such as demographic, industrial, land use, and technological changes—are not directly addressed in this section. Note that historically, non-climate drivers have significantly impacted freshwater resources; understanding the contribution of these different drivers to changes in the freshwater resource provides important information regarding how to effectively and efficiently address (and anticipate) changes. For example, while increases in precipitation and intense rainfall are projected to decrease freshwater quality in parts of the United States, strategies that aim to reduce sediment, nutrient, and contaminant loads at the source remain the most effective management responses. Strategies that reduce water demands (e.g., concerning agriculture, there are ways to get the water to the crop that are more efficient and thereby reduce overall demand) can also be employed in areas subject to increasing water scarcity.

5.5.2.1.1 Summary

Overall, the most recent freshwater resources studies cited herein confirm previous results and add to the growing body of modeling results and field observations that indicate substantial impacts on freshwater resources, and implications on their sustainability, as a result of climate change. In general, global warming is expected to cause wet regions to become wetter and dry regions to become drier globally and within the United States (IPCC 2014a, GCRP 2014, Liu and Allan 2013). Potential risks to freshwater resources are expected to increase with increasing GHG emissions; for example, higher emissions are projected to result in less renewable water for greater numbers of people (IPCC 2014b). Although some positive impacts are anticipated, including reductions in water stress and increases in water quality in some areas as a result of increased runoff, the negative impacts are expected to outweigh positive impacts (IPCC 2014b, GCRP 2014).

Globally, widespread observations and evidence of changes in flood magnitude and frequency or of surface water and groundwater drought frequency as a result of climate change do not exist; however, projections imply increases in both drought risk (particularly in dry regions) and flood risk globally and within the United States. Changes in climate will affect water demand, including expected significant increases in irrigation water demand for some regions. Projected water shortages, general variability in supply, and increasing flood risk pose serious challenges for water resource management (GCRP 2014).

5.5.2.1.2 Observations and Projections of Climate Impacts

<u>Precipitation, Stream Flow, Runoff, and Surface Water</u>

In recent decades, annual average precipitation increases have been observed across the Midwest, Great Plains, the Northeast, and Alaska, while decreases have been observed in Hawaii and parts of the Southeast and Southwest (Walsh et al. 2014). Globally, for mid-latitude land areas of the northern hemisphere, annual average precipitation has likely increased since 1901. For other latitudinal zones, long-term trends in average precipitation are uncertain due to data quality, data completeness, or disagreement among available estimates (IPCC 2014a).

Detected trends in streamflow and runoff are generally consistent with observed regional changes in precipitation and temperature (IPCC 2014b). In the United States (1951 to 2002), increases in runoff were observed in the Mississippi and Missouri regions, while runoff decreases were observed in the Pacific Northwest and southern Atlantic-Gulf regions (IPCC 2014b citing Kalra et al. 2008; GCRP 2014 citing Luce and Holden 2009), with no clear trends in much of the rest of the continental United States (GCRP 2014 citing McCabe and Wolock 2011). A recent study (Patterson et al. 2013) found climate contributed to increased streamflow (average of 14 percent) in the South Atlantic over the time period 1970–2005.

In a global analysis of simulated streamflows (1948 to 2004), about one-third of the top 200 rivers showed significant trends in discharge; 45 recorded decreases and only 19 recorded increases (IPCC 2014b citing Dai et al. 2009). Globally, in regions with seasonal snow storage, warming has led to earlier occurrence of the maximum streamflows from snowmelt during the spring and increased winter streamflows because more winter precipitation falls as rain instead of snow (IPCC 2014b citing Clow 2010, Korhonen and Kuusisto 2010, Tan et al. 2011).

The projected patterns of runoff change (and the uncertainty) are largely driven by projected changes in precipitation. Average annual precipitation is projected to increase across the northern United States and decrease in the southern United States, especially the Southwest (GCRP 2014 citing Kennedy et al. 2010). Average global precipitation is projected to increase over the next century; generally, wet places are expected to get wetter and dry places are expected to get drier (IPCC 2014a).

Basins in the southwestern United States and southern Rockies are projected to experience gradual runoff declines during this century. Basins in the Northwest to north-central United States are projected to experience little change through the middle of this century and increases by late this century. Projected changes in runoff differ by season, with cool season runoff increasing over the west coast basins from California to Washington and over the north-central United States. Basins in the southwestern United States and southern Rockies are projected to see little change to slight decreases in the winter months. Warm season runoff is projected to decrease substantially over a region spanning southern Oregon, the southwestern United States, and southern Rockies, and change little or increase slightly north of this region (GCRP 2014).

Globally, average annual runoff is projected to increase at high latitudes and in the wet tropics and to decrease in most dry tropical regions. However, for some regions there is considerable uncertainty in the magnitude and direction of change, specifically in China, south Asia, and large parts of South America. Continued loss of glacier ice implies a shift of peak discharge from summer to spring, except in monsoonal catchments, and possibly a reduction of summer flows in the downstream parts of glacierized catchments (IPCC 2014b).

Groundwater

In large regions of the Southwest, Great Plains, Midwest, Florida, and some other coastal areas, groundwater aquifers are susceptible to the combined stresses of climate and water use changes. However, both globally and in the United States, attribution of observed changes in groundwater level, storage, or discharge to climatic changes is difficult due to additional influences of land use changes and groundwater abstractions (IPCC 2014b citing Stoll et al. 2011), and the extent to which groundwater abstractions have already been affected by climate change is not known.

Ensemble studies of the potential impact of climate change on groundwater recharge and partially also on groundwater levels were done for the globe (IPCC 2014b citing Portmann et al. 2013), the Pacific coast of the United States and Canada (IPCC 2014b citing Allen et al. 2010b), the semi-arid High Plains aquifer of the United States (IPCC 2014b citing Crosbie et al. 2013b, Ng et al. 2010), and other regions. The range over the climate models of projected groundwater changes was large, from significant decreases to significant increases for the individual study areas, and the range of percentage changes of projected groundwater recharge mostly exceeded the range of projected precipitation changes. Both globally and in the United States, sea-level rise, storms and storm surges, and changes in surface water and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands (GCRP 2014).

Snow, Ice Cover, Permafrost, and Glaciers

Rising temperatures across the United States have reduced lake ice, sea ice, glaciers, and seasonal snow cover over the last few decades (GCRP 2014 citing AMAP 2011). Sea ice in the Arctic has decreased dramatically since the late 1970s, particularly in summer and autumn. Glaciers are retreating and/or thinning in Alaska and in the lower 48 states. In addition, permafrost temperatures are increasing over Alaska and much of the Arctic. In most parts of the world, glaciers are losing mass (Gardner et al. 2013). Nearly all glaciers are too large for equilibrium with the present climate, committing them to change during much of the 21st century. Decreases in the extent of permafrost and increases in its average temperature are widely observed (IPCC 2014a citing Rabassa 2009).

Nearly all studies to date published in the peer-reviewed literature agree that if heat-trapping gas concentrations continue to rise, lake ice, sea ice, glaciers, and seasonal snow cover will be reduced (IPCC 2014a). For example, an essentially ice-free Arctic Ocean is expected sometime during this century (GCRP 2014 citing Stroeve et al. 2012). In the United States, Great Lakes ice should follow a similar trajectory. Basins watered by glacial melt in the Sierra Nevada, Glacier National Park, and Alaska may experience increased summer riverflow in the next few decades, until the amounts of glacial ice become too small to contribute to riverflow (GCRP 2014 citing Basagic and Fountain 2011; Hall and Fagre 2003; Hodgkins et al. 2005).

Extreme Rainfall, Floods, and Droughts

The number and intensity of very heavy precipitation events have been increasing significantly across most of the United States. For example, from 1950 to 2007, daily precipitation totals with 2-, 5-, and 10-year average recurrence periods increased in the Northeast and western Great Lakes (GCRP 2014 citing DeGaetano 2009, Mishra and Lettenmaier 2011). According to the NCA report, river floods have been increasing in the Northeast and Midwest and decreasing in the Southwest and Southeast (GCRP 2014 citing Villarini et al. 2009, Villarini and Smith 2010, Hirsch and Ryberg 2012, Gutowski et al. 2008, and Karl and Knight 1998). However, GCRP (2014a) cites Hirsch and Ryberg (2012) in concluding that there is no strong evidence for trends in observed flooding in the United States. Hirsh and Ryberg (2012) took a different approach than other studies in focusing on finding statistical evidence of a historical relationship between global mean CO_2 and flood magnitudes in the coterminous United States, and while they did not find strong statistical evidence for flood magnitudes increasing, they found a statistically significant negative relationship between global mean CO_2 and flood magnitudes in the southwest. These decreases are consistent with the NCA report findings, and are not surprising, as short duration very heavy precipitation events often occur during the summer and autumn when rivers are generally low.

There is limited evidence that anthropogenic climate change has affected the frequency and magnitude of floods at a global scale (Kundzewicz et al. 2013). The strength of the evidence is limited mainly by lack of long-term records from unmanaged catchments. Moreover, in the attribution of detected changes it is difficult to distinguish the roles of climate and human activities. However, recent detection of trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at a regional scale. More locations show increases in heavy precipitation than decreases (Seneviratne et al. 2012). Flood damage costs worldwide have been increasing since the 1970s, although this is partly due to increasing exposure of people and assets (Handmer et al. 2012).

In the United States, there is no evidence that surface water and groundwater drought frequency has changed over the last few decades as a result of climate change. Droughts occur on time scales ranging from season-to-season to multiple years and even multiple decades. There has been no universal trend detected in the overall extent of drought across the continental United States since 1900. However, in the Southwest, wide-spread drought in the past decade has reflected both precipitation deficits and higher temperatures in ways that resemble projected changes (GCRP 2014 citing Cayan et al. 2010, Hoerling et al. 2012). Globally, meteorological (rainfall) and agricultural (soil moisture) droughts have become more frequent since 1950 in some regions, including southern Europe and western Africa (IPCC 2013 citing Seneviratne et al. 2012). In simulations of drought at the global scale in 1963–2000, strong correlations were noted between El Niño–Southern Oscillation events and hydrological droughts, and—particularly in dry regions—low correlations between meteorological and hydrological droughts, which suggests that hydrological droughts cannot necessarily be inferred from rainfall deficits (van Huijgevoort et al. 2013).

The number and magnitude of the heaviest precipitation events is projected to increase everywhere in the United States (GCRP 2014 citing Kharin et al. 2013). Heavy precipitation events that historically occurred once in 20 years are projected to occur as frequently as every 5 to 15 years by late this century (GCRP 2014 citing Groisman et al. 2012). Floods that are closely tied to heavy precipitation events, such as flash floods and urban floods, as well as coastal floods related to sea-level rise and the resulting increase in storm surge height and inland impacts, are expected to increase (GCRP 2014). Over the 21st century and in the absence of global GHG mitigation, projections suggest increases in inland flood damages in the contiguous United States both in terms of the scale of damage and its geographic extent (EPA 2015g). The greatest damages are projected to occur in the eastern U.S. and Texas, with damages in these regions ranging from US$1.0 billion to US$3.7 billion in 2100 (EPA 2015g). Estimates of annual flood cost increases in the United States at the end of the 21st century range from about US$7 billion to US$19 billion (2010 dollars), depending on assumptions about increasing rainfall intensity and urban wealth, the economic growth rate, and the emissions scenario (Ntelekos et al. 2010). Globally, projections indicate variations in the frequency of floods and increases in global flood risk in the future due to climate change. As the level of GHG emissions rises, increasing numbers of people are expected to be exposed to 100-year flood events (IPCC 2014c).

Dry spells are also projected to increase in length in most regions, especially in the southern and northwestern portions of the contiguous United States. In the absence of global GHG mitigation, climate change is projected to result in a pronounced increase in the number of droughts in the southwestern United States; GHG mitigation sufficient to limit future warming to 2°C (3.6°F) would lead to a substantial reduction in the number of drought months in the southwestern United States (EPA 2015h). Projected changes in total average annual precipitation are generally small in many areas, but both wet and dry extremes (heavy precipitation events and length of dry spells) are projected to increase substantially almost everywhere. Long-term (multi-seasonal) drought conditions are also projected to increase in parts of the Southeast and possibly in Hawaii and the Pacific Islands (GCRP 2014). Except in the few areas where increases in summer precipitation compensate, summer droughts are expected to intensify almost everywhere in the continental United States (GCRP 2014 citing Trenberth et al. 2004) due to longer periods of dry weather and more extreme heat (GCRP 2014 citing Gao et al. 2011), leading to more moisture loss from plants and earlier soil moisture depletion in basins where snowmelt shifts to earlier in the year.

Climate change is likely to increase the frequency of droughts in presently dry regions by the end of this century (under the high [RCP8.5] scenario), which in turn is likely to increase the frequency of short hydrological droughts (less surface water and groundwater) in these regions. Very few studies have isolated the variations over time in hydrological (streamflow) drought due to climate change alone, largely because there are few long-term records from catchments where there have not been direct human interventions (e.g., changes in impermeable surface as well as changes in climate). A recent study (Prudhomme et al. 2014) using an ensemble of 35 simulations showed a likely increase in the global severity of drought by the end of 21st century, with regional hotspots including South America and Central and Western Europe in which the frequency of drought increases by more than 20 percent.

<u>Water Quality</u>

There are well established links among fertilizer use, nutrient pollution, and river discharge, and many studies show that recent increases in rainfall in several regions of the United States have led to higher nitrogen amounts carried by rivers (Northeast, California, and Mississippi Basin) (GCRP citing Barnett et al. 2008, Bonfils et al. 2008, Das et al. 2009, Hidalgo et al. 2009, Pierce et al. 2008, Pierce and Cayan 2013, Gan et al. 2013, Hodgkins and Dudley 2006a, Hodgkins and Dudley 2006b, Feng and Hu 2007). Over the past 50 years, due to both climate and land use change, the Mississippi Basin is yielding an additional 32 million acre-feet of water each year laden with materials washed from its farmlands. This flows into the Gulf of Mexico, which is the site of the nation's largest low oxygen "dead" zone (GCRP 2014 citing Hodgkins et al. 2002).

Globally, most observed changes of water quality due to climate change are known from isolated, short-term studies, mostly of rivers or lakes in high-income countries. The most frequently reported change is more intense eutrophication (i.e., an increase in phosphorus and nitrogen in freshwater resources) and algal blooms (i.e., excessive growth of algae) at higher temperatures, or shorter hydraulic retention times and higher nutrient loads resulting from increased storm runoff. Positive reported impacts include reductions in the risk of eutrophication when nutrients were flushed from lakes and estuaries by more frequent storms and hurricanes (IPCC 2014b citing Paerl and Huisman 2008). For rivers, all reported impacts on water quality were negative. Studies of impacts on groundwater quality are limited and mostly report elevated concentrations of fecal coliforms during the rainy season or after extreme rain events (IPCC 2014b citing Auld et al. 2004, Curriero et al. 2001, Jean et al. 2006, Seidu et al. 2013, Tumwine et al. 2002, 2003). In general, the linkages between observed impacts on water quality and climate should be interpreted cautiously and at the local level.

Globally, and within the United States, there are few projections of the impacts of climate change on water quality; where available, their uncertainty is high. Areas of the United States that are projected to see increases in precipitation, and increases in intense rainfalls, like the Northeast, Midwest, and mountainous West (IPCC 2014b citing Roy et al. 2012), are expected to see increases in excess nutrients, dissolved oxygen concentrations, and sediments transported to rivers. One study suggests that downstream and coastal impacts of increased nitrogen inputs could be profound for the Mississippi Basin (GCRP 2014 citing Justić et al. 1996). Rising air temperatures, increased frequency and duration of droughts, and associated low water levels increase nutrient concentrations and residence times in streams, potentially increasing the likelihood of harmful algal blooms and low oxygen conditions (GCRP 2014 citing Whitehead et al. 2009). Concerns over such impacts and their potential link to climate change are rising for many U.S. regions including the Great Lakes (GCRP citing Stumpf et al. 2012), Chesapeake Bay (GCRP 2014 citing Howarth et al. 2006), and the Gulf of Mexico (GCRP 2014 citing Justić et al. 2005, McIsaac et al. 2002, Godsey et al. 2009). Unmitigated climate change is projected to have negative impacts on water quality in the United States, particularly in the Southwest and parts of Texas, primarily as a result of warming of water bodies across the country (EPA 2015g). Changes in sediment transport are expected to vary regionally and by land-use type, with potentially large increases in some areas (GCRP 2014 citing Nearing et al. 2005), resulting in alterations to reservoir storage and river channels, affecting flooding, navigation, water supply, and dredging.

5.5.2.1.3 Adaptation

Climate change affects water supply, demand, and the ways water is used within and across regions and economic sectors. In the United States, the Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand. Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses. Increasing flood risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the United States. Without global GHG mitigation, damages associated with the changes in supply and demand of water across the United States are estimated to range from approximately $7.7 billion to $190 billion in 2100, and are particularly costly in the Southeastern United States (EPA 2015g). The spread of this range indicates that the effect of climate change on water supply and demand is highly sensitive to projected changes in runoff and evaporation, both of which vary greatly across future climate projections and by U.S. region (EPA 2015g). In addition, climate change is projected to reduce raw water quality, posing risks to drinking water quality even with conventional treatment (IPCC 2014b). Climate change challenges water management because it invalidates stationarity—the perception that climate varies around a predictable mean based on the experience of the last century. A move away from stationary conditions suggests that past management practices will become increasingly ineffective and that water management can benefit by the adoption of iterative, risk-based, and adaptive approaches. Given the uncertainty associated with climate change, adaptation planning often involves anticipatory scenario-based planning and the identification of flexible, low-regrets strategies (e.g., water conservation and demand-side management) to maximize resilience. In the United States and globally, current and projected impacts of climate change on water resources have sparked several responses by water resource managers that can be built on. In 2011, federal agencies, which manage most of the freshwater resources in the United States, worked with stakeholders to develop a National Action Plan for managing freshwater resources in a changing climate to help ensure adequate freshwater supplies, while also protecting water quality, human health, property, and aquatic ecosystems (ICCATF 2011). Water utilities are determining ways to adjust operation and maintenance schedules. Water conservation and demand management are also being promoted as important non-structural, low-regrets approaches for managing water supply. Barriers to progress include lack of human and institutional capacity, financial resources, awareness, and communication (Browning-Aiken et al. 2007, Burton 2008, Butscher and Huggenberger 2009, Zwolsman et al. 2010). Finally, global GHG mitigation sufficient to limit future warming to 2°C (3.6°F) is estimated to substantially decrease damages associated with the supply and demand of water across the United States by the end of the century. Global GHG mitigation is projected to preserve water supply and demand conditions similar to those experienced today (EPA 2015g).

5.5.2.2 Terrestrial and Freshwater Ecosystems

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on the terrestrial and freshwater ecosystems in the United States and globally. Ecosystems include all living organisms and their environs that interact as part of a system (GCRP 2014 citing Chapin et al. 2011). These systems are often delicately balanced and sensitive to internal and external pressures due to both human and non-human influences. Ecosystems are of concern to society because they provide beneficial "ecosystem services" such as jobs (e.g., from fisheries and forestry), fertile soils, clean air and water, recreation, and aesthetic value (GCRP 2014 citing Millennium Ecosystem Assessment 2005).

5.5.2.2.1 Summary

Terrestrial and freshwater ecosystems in the United States and around the world are experiencing rapid and observable changes. Steadily warming temperatures and rising atmospheric CO_2 concentration, as well as changing precipitation patterns, are already leading to shifting species ranges and earlier spring migrations and are threatening the ability of existing habitats to thrive (EPA 2015g, GCRP 2014, IPCC 2014b). Climate change is also affecting the relative timing of species' life-cycle events, referred to as phenology, which can upset existing species 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. 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.

5.5.2.2.2 Observations and Projections of Climate Impacts on Ecosystems

Phenology

Recent global satellite and ground-based data further support conclusions from earlier reports (including IPCC AR4) that indicated that phenology shifts have been observed, particularly across temperate latitudes of the northern hemisphere. These shifts include earlier spring events, such as breeding, budding, flowering, and migration, which have been observed in hundreds of plant and animal species (IPCC 2014b citing Menzel et al. 2006, Cleland et al. 2007, Parmesan 2007, Primack et al. 2009, Cook et al. 2012a, Peñuelas et al. 2013). Leaf unfolding and flowering in spring and summer have, on average, advanced by 1 to 3 days per decade in Europe, North America, High Arctic Regions, and Asia over the past 35 to 152 years (study-dependent) (IPCC 2014b citing Cook et al. 2008, Cook et al. 2012b, Menzel et al. 2006, Primack et al. 2009, Ma and Zhou 2012, Høye et al. 2007).

For amphibians, increasing regional temperatures are also associated with earlier calling and mating and shorter time to maturity. In the eastern United States, there could be as much as a 50 percent turnover in amphibian species by the end of the century as a result of changes in climate due to unfavorable future conditions for current species and to phenological mismatches that result in unfavorable breeding and egg-laying conditions (GCRP 2014 citing Lawler et al. 2010 and Todd et al. 2011). The seasonal timing of bird migration and egg-laying has also changed, associated with the increase of temperature in breeding grounds and migration routes; such changes are projected to continue (GCRP 2014 citing Miller-Rushing et al. 2008, Van Buskirk et al. 2008, Jones and Cresswell 2010, Swanson and Palmer 2009, and Wiebe and Gerstmar 2010; IPCC 2014b citing Thorup et al. 2007). In the northern hemisphere, earlier egg-laying dates (by about 3.5 days per decade) have been observed for 41 species (IPCC 2014b citing Parmesan 2007). A mismatch in timing between food abundance, breeding, and migration is also associated with decreased average egg size (Potti 2008).

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.

Species' Range and Ecosystem Shifts and Localized Extirpation or Global Extinction of Species

Species respond to stressors such as climate change by phenotypic[42] or genotypic[43] modifications, migrations, or extinction (IPCC 2014b citing Dawson et al. 2011, Bellard et al. 2012, Peñuelas et al. 2013). Changes in the distribution of species have occurred across a wide range of taxonomic groups and geographical locations. Recent studies have reinforced earlier conclusions in the IPCC AR4 that over the past several decades, a pole-ward (in latitude) and upward (in elevation) extension of various species' ranges has been observed that is probably attributable to increases in temperature (IPCC 2014b). In both terrestrial and freshwater ecosystems, plants and animals are moving up in elevation—at approximately 36 feet per decade—and in latitude—at approximately 10.5 miles per decade (GCRP 2014 citing Chen et al. 2011). In some mountainous areas of the northern hemisphere, including in Alaska, tree lines have shifted to higher altitudes over the past century. Many northern communities have seen shifts at forest/tundra, broadleaf/conifer, and shrubland/conifer boundaries due to warming (GCRP 2014 citing Beck et al. 2011, Dial et al. 2007, Lloyd and Fastie 2003, Suarez et al. 1999, Wilmking et al. 2004, Millar et al. 2004, Beckage et al. 2008, Allen and Breshears 1998).

Climate-related extinctions are linked to the following factors: physiological tolerances for temperature, other physical factors (fire disturbance, melting ice caps, sea-level rise), decreases in species upon which other species rely, increases in invasive species, and temporal mismatches (such as short windows for migration, and breeding periods that no longer coincide with peak bloom periods which in turn result in food shortages—see phenology discussion) (Cahill et al. 2012). Studies agree that localized extinctions ("extirpations") of species are expected to continue, and probably occur more quickly, over the coming century. Over the 21st century, species range shifts, as well as extirpations, are likely to result in significant changes in ecosystem plant and species mixes, creating entirely new ecosystems (GCRP 2014 citing Staudt et al. 2013, Sabo et al. 2010, Cheung et al. 2009, Lawler et al. 2010, and Stralberg et al. 2009). Since the IPCC AR4, studies have confirmed with *high confidence* that climate change will exacerbate the extinction risk for terrestrial and freshwater species over the 21st century; however, there is low agreement on the number of species that are at risk (ranging from 1 to 50 percent) (IPCC 2014b).

Of particular concern for aquatic species, including fish, is that the combination of increased water demand (withdrawals) and changes in climate is likely to result in freshwater habitat loss. In the United States, under the moderate (A1B) emissions scenario, close to half of the western states' trout habitat would be lost by 2080 (GCRP 2014 citing Wenger et al. 2011). Previously uncommon species of fish, such as Pacific salmon, have been observed in aquatic systems of the Canadian Arctic in recent years, as a result of expanded ranges from warming waters (ACIA 2004). There is *high confidence* that some fish will be threatened with extinction over the long term, as the pace of warming in rivers and lakes exceeds the pace with which fish are able to migrate to more suitable habitats (IPCC 2014b). Recent projections also indicate that coldwater fisheries will be limited almost entirely to mountainous western states by 2100, disappearing from Appalachia altogether. In the United States, overall coldwater fish habitats are projected to decrease in area by 62 percent in the same timeframe. However, warmwater and rough stream fish habitats could increase by 1.3 million acres, particularly in Appalachia, northern New England, and non-mountainous portions of western states (EPA 2015g).

Additionally, in areas that experience heavier or more frequent precipitation events, an increase in phosphorus and nitrogen in freshwater resources (eutrophication) due to increased agricultural runoff is

[42] Referring to an organism's observable traits, such as color or size.

[43] Referring to an organism's genetic makeup.

probable in the Northeast, California, and Mississippi Basin (GCRP 2014 citing Howarth et al. 2012, Howarth et al. 2006, Sobota et al. 2009, Justić et al. 2005, and McIsaac et al. 2002). 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.

Species Morphology[44] and Reproduction

Changes in morphology and reproductive rates have been attributed to climate change. For example, the egg sizes of some bird species are changing with increasing regional temperatures (Potti 2008). At least one study indicates that birds in North America are experiencing decreased body size due to changes in climate (Van Buskirk et al. 2010). Increases in predatory populations as a result of regional warming put some bird populations at risk due to increased vulnerability of their eggs to predators; additionally, declines in available habitat put birds at risk when they are unable to find appropriate nesting and egg-laying spots. This is especially of concern for seabirds and birds that rely on rainforest ecosystems (Wormworth and Mallon 2010). Many northern insects have a 2-year life cycle, and warmer winter temperatures allow a larger fraction of overwintering larvae to survive. For example, the invasive mountain pine beetle has expanded its range in the western United States and Canada into areas previously considered too cold for its survival (IPCC 2014b citing Raffa et al. 2008).

Changes in the Carbon Storage Capacity of Terrestrial Ecosystems

Terrestrial plants store atmospheric CO_2; increasing terrestrial plant mass will increase carbon storage, at least over the short term. In the first decade of the 21st century, net primary productivity among terrestrial systems was estimated to be 5 percent greater than pre-industrial productivity, which is equivalent to increased carbon storage of about 2.6 petagrams (1 pentagram equals 1 quadrillion or $1x10^{15}$ grams) (IPCC 2014b). Many studies have indicated that accelerated tree growth occurred over the 20th century (IPCC 2014b citing Briffa et al. 2008), which is associated with increased temperature that supports vegetation growth and can also be associated with direct CO_2 fertilization (IPCC 2014b). Conversely, in areas experiencing extended drought (such as the western United States in 2014) water stress results in decreased tree growth (IPCC 2014b). For some ecosystems, the factors that affect the balance between carbon storage or carbon source are not well understood.

A recent study evaluated the capacity of the Greater Yellowstone Ecosystem (GYE) conifer forests to act as a carbon storage pool under changing climate conditions and new fire regimes. Using climate projections downscaled to the ecosystem, and using these projections in the CENTURY model (a dynamic ecosystem process model), the authors simulated carbon storage in the GYE conifer forests over the 21st century. They found that more than one occurrence of wildfire within a 90-year period will cause lodgepole pines to shift from acting as a net carbon sink to a net carbon source. Although the projected warming conditions will likely increase forest productivity, thereby increasing carbon storage, net storage will not occur at a rate sufficient to recover more than 85 percent of the carbon lost during the initial wildfire. The authors concluded that while the magnitude of the shift is uncertain, the potential of the GYE to store carbon will decline under all warming climate scenarios (IPCC 2014b citing Westerling et al. 2011).

Several recent studies have evaluated terrestrial vegetation productivity and the associated carbon storage in response to changes in carbon, nitrogen, and phosphorous nutrient cycles. The authors

[44] Referring to an organism’s structural or anatomical features (e.g., egg size, wing shape, or even of the organism as a whole).

indicate that in addition to nitrogen fixation, carbon storage in vegetation is likely to be closely linked to interactions between carbon and phosphorus nutrient cycles. As plants gain more biomass, their net storage of carbon might be limited by nutrient availability in soils (Finzi et al. 2011). Within a few decades, it is possible that changes in temperature and precipitation patterns will exceed nitrogen and CO_2 as key drivers of ecosystem productivity (IPCC 2014b).

Ecological Tipping Points and Biodiversity

A 2010 report by the Convention on Biological Diversity (IPCC 2014b citing Leadley et al. 2010) described 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 5.5.2.10, ecological tipping points[45] 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 and 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 hard to roll back; managing these conditions is often very difficult (IPCC 2014b citing Leadley et al. 2010). Leadley et al. (2010) evaluated the potential tipping point mechanisms and their impacts on biodiversity and ecosystem services for several ecosystems. Examples include (1) warming tundra that will lower albedo, providing a warming feedback that will result in further thawing of tundra and (2) the large-scale changes in Amazonian rainforests to agricultural lands, resulting in decreased local/regional rains, promoting further decline of trees.

Forest ecosystems and services are at risk of greater fire disturbance when they are exposed to increased warming and drying, as well as declines in productivity and increases in insect disturbances (such as pine beetles). Boreal fire regimes have become more intense in terms of areas burned, length of fire season, and hotter, more energetic fires (IPCC 2014b citing Girardin and Mudelsee 2008, Macias Fauria and Johnson 2008, Kasischke et al. 2010, Turetsky et al. 2011, Mann et al. 2012, and Girardin et al. 2013a). Fires of greater intensity burn soils to greater depths, encouraging replacement of coniferous species with deciduous trees—further enhancing the species shifts due to warming (IPCC 2014b citing Johnstone et al. 2010 and Bernhardt et al. 2011). Cascading effects in forests are possible when fire-related changes in forest composition result in reduced capacity as a carbon sink and lower albedo, both of which factor into further warming, putting forests at even greater risk of fire and dieback (IPCC 2014b citing Bond-Lamberty et al. 2007, Goetz et al. 2007, Welp et al. 2007, Euskirchen et al. 2009, Randerson et al. 2006, Jin et al. 2012, and O'Halloran et al. 2012). Recent models project that by the end of this century, over 5 million additional acres will burn each year in the United States, compared to today's rates. Western states are projected to see a 43 percent increase in the area affected by fire, while the Southwest is expected to see an increase of approximately 140 percent over the historical baseline (2000–2009) (EPA 2015g).

5.5.2.2.3 Adaptation

Ecosystem adaptation to climate change can be the result of human activities intended to protect them or can occur naturally by responses within the ecosystem. In the context of natural resource management, adaptation is about managing changes (GCRP 2014 citing Staudinger et al. 2012, Link et al. 2010, and West et al. 2009). The ability or inability of ecosystems to adapt to change is referred to as

[45] An ecological tipping point is described by IPCC (2014), in reference to the potential for Amazonian ecosystem shifts, as "a large-scale, climate-driven, self-reinforcing transition" of one ecosystem into another type.

adaptive capacity. There could be notable regional differences in the adaptive capacity of ecosystems, and adaptive capacity is moderated by anthropogenic influences and capabilities. The ultimate impact of climate change on ecosystems depends on the speed and extent to which these systems can adapt to a changing climate.

Some adaptation strategies include habitat manipulation, conserving populations with more genetic diversity and/or behaviors, relocation (or assisted migration), and offsite conservation (such as seed banking and captive breeding) (GCRP 2014 citing Weeks et al. 2011, Peterson et al. 2001, Cross et al. 2013, and Schwartz et al. 2012). Significant modifications to existing ecosystem management practices are probably the most important—as well as the most challenging—changes that are required for adaptation. NCA (2014) indicates that it will be very difficult for existing management goals to be achieved in the face of a changing climate; that is, the effectiveness of existing strategies and approaches is likely to be diminished.

5.5.2.3 Ocean, Coastal, and Low-lying Areas

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on ocean, coastal, and low-lying areas in the United States and globally. Ocean systems cover approximately 71 percent of the Earth's surface and include many habitats that are vital for coastal economies. Coastal systems and low-lying areas include all areas near the mean sea level. Coastal systems consist of both natural systems (i.e., rocky coasts, beaches, barriers, sand dunes, estuaries, lagoons, deltas, river mouths, wetlands, and coral reefs) and human systems (i.e., the built environment, institutions, and human activities) (IPCC 2014b).

Oceans and coastal systems are vulnerable to both warming temperatures and various anthropogenic impacts. A large portion of ocean and coastal ecosystems around the globe has been substantially degraded or lost altogether. The population of individuals living in coastal areas continues to increase worldwide, increasing environmental pressures (e.g., physical alteration, habitat degradation and destruction, water withdrawal, overexploitation, pollution, and the introduction of non-native species) that threaten the very resources that make the coastal zones desirable. Moreover, climate change has the potential to compound these pressures, leaving these systems particularly vulnerable to warming water temperatures, sea-level rise, water acidification, and increased extreme weather events.

5.5.2.3.1 Summary

Overall, the most recent ocean and coastal systems studies cited herein confirm previous results and add to the growing body of modeling results and field observations that indicate substantial impacts on ocean resources—and implications on their sustainability—as a result of climate change. In general, ocean temperatures have risen over the past century and will continue to increase in the future, with impacts on climate, ocean circulation, chemistry, and ecosystems. Between 1971 and 2010, global oceans have absorbed 93 percent of all extra heat stored in earth's systems (UN 2016). Ocean systems absorb approximately 25 percent of anthropogenic CO_2 emissions, leading to ocean acidification, which affects the formation of some marine species that are crucial to ocean health (GCRP 2014, UN 2016). The combination of warming and acidification across water bodies has adverse effects on key habitats such as coral reefs and results in changes in distribution, abundance, and productivity of many marine species.

Globally, there has been a net migration of individuals to coastal regions, which has resulted in greater pressures on already-vulnerable coastal systems and a greater number of individuals and assets exposed to climate impacts. Transportation, energy, and water infrastructure are increasingly vulnerable to higher sea levels, storm surges, flooding, and erosion. Economic activity dependent on ports, tourism, and fisheries faces disruption due to climate-related hazards. The net global benefit of protecting against coastal flooding and land loss is larger than the cost of inaction; the cost of adaptation will vary greatly from region to region (IPCC 2014b).

5.5.2.3.2 Observations and Projections of Climate Impacts

Anthropogenic Pressures

Climate change impacts on sea-level rise and ocean temperatures could affect large coastal populations. Approximately 600 million people live in the Low Elevation Coastal Zone (IPCC 2014b citing McGranahan et al. 2007), with approximately 270 million people exposed to the 1-in-100 year extreme sea level (Jongman et al. 2012). Globally, there has been a net migration to coastal areas, largely in flood- and cyclone-prone regions (IPCC 2014b citing de Sherbinin et al. 2012). The five nations with the highest exposure to climate coastal impacts are Bangladesh, China, Vietnam, India, and Indonesia (IPCC 2014b citing McGranahan et al. 2007 and Bollman et al. 2010, Jongman et al. 2012). Without adaptation, hundreds of millions of people will be displaced due to flooding and land loss by the year 2100, with the majority from east, southeast, and south Asia (Jongman et al. 2012).

In the United States, 120 million Americans live in counties that either border the ocean or the Great Lakes and/or are located within a 100-year coastal floodplain (GCRP 2014 citing Cooley et al. 2012). By 2100, this population is expected to increase to 131 million people, with significant numbers arriving in high-hazard zones (GCRP 2014 citing EPA 2010). These communities are at risk for episodic localized flooding associated with storm surge and coastal flooding from sea-level rise. Those at risk include a substantial number of individuals in a *high social vulnerability* category, with less economic or social mobility and are less likely to be insured (GCRP 2014). For example, in California, approximately 18 percent of those exposed to high risk will fall into a *high social vulnerability* category with less ability to adapt (GCRP 2014 citing Cooley et al. 2012).

Changes in precipitation patterns have complex impacts on coastal areas. Areas with increased precipitation will see heavier runoff from inland areas and an increased risk of extreme runoff and flooding while areas with decreased precipitation will see an increase in drought and a decrease in freshwater inflows (GCRP 2014). Over the past 3 decades, there has been an overall increase in storm activity, frequency, and intensity near the northeast and northwest coastlines (GCRP 2014 citing Vose et al. 2012b). Extreme storms can erode or remove sand dunes and other land elevations, exposing them to inundation and further change (GCRP 2014).

Coastal energy, water, and transportation infrastructure are highly sensitive to higher sea levels, storm surges, inland flooding, erosion, and other climate-related changes (GCRP 2014, IPCC 2014b citing Handmer et al. 2012, Horton et al. 2010, Hanson and Nicholls 2012, and Aerts et al. 2013). The unique characteristics of coastal infrastructure increase its vulnerability and have the potential to alter coastal life and disrupt coast-dependent economic activities (GCRP 2014). Many coastal roads and bridges are already affected during storm events and extreme high tides (GCRP 2014 citing California King Tides Initiative 2012). Severe storms have been particularly disruptive to transport and power and water supplies (IPCC 2014b citing CCSP 2008, Horton et al. 2010, and Jacob et al. 2007). Weather-related disruptions to port activities can impact multiple segments of supply chains (IPCC 2014b citing Becker et al. 2012, 2013) and hurricanes and flooding of underground infrastructure can have long-term effects (IPCC 2014b citing Chisolm and Matthews 2012).

Ecological Changes

Rising water temperatures and other climate-driven changes (e.g., salinity, acidification, and altered river flows) will impact the survival, reproduction, and health of coastal plants and animals (GCRP 2014, UN 2016). Shifts in the distribution of species and ranges, changes in species interactions, and reduced biodiversity cause fundamental changes in ecosystems and can adversely impact economic activities such as fishing (GCRP 2014). Species with narrow physiological tolerance to change, low genetic diversity, specific resource requirements, or weak competitive abilities will be particularly vulnerable to climate change (GCRP 2014 citing Dawson et al. 2011 and Feder 2010). Under some climate change scenarios, as much as 60 percent of the global ocean's biomass could be affected (either positively or negatively), including changes in the range of large fish species such as tuna and cod along with a decrease in productively of these species (incurring economic as well as ecological impacts) (UN 2016).

Studies indicate that 75 percent of the world's coral reefs are threatened due to climate change and localized stressors (GCRP 2014 citing Burke et al. 2011, Dudgeon et al. 2010, Hoegh-Guldburg et al. 2007, Frieler et al. 2013, and Hughes et al. 2010). Increases of only 1–2 °C (1.8–3.6°F) compared to normal local seasonal maxima are enough to cause bleaching (UN 2016). A third of reef-building corals are listed as vulnerable, endangered, or critically endangered (GCRP 2014 citing Carpenter et al. 2008) and the National Oceanic and Atmospheric Administration is proposing to list 66 species of coral under the Endangered Species Act (GCRP 2014 citing Brainard et al. 2011 and NMFS 2012). In the United States, warming waters have driven eelgrass in the Chesapeake Bay and black abalone in California to the edge of extinction (GCRP 2014 citing Moore et al. 2008, Moore et al. 2012, Altstatt et al. 1996, and Neumann et al. 2010). Fisheries productivity is projected to decline in the contiguous United States and increase in parts of Alaska (GCRP 2014 citing Cheung et al. 2009). The potential for coastal ecosystems to pass a "tipping point" threshold is of particular concern as these changes can be irreversible (GCRP 2014 citing Hoegh-Guldberg and Bruno 2010).

Sea Level

There is strong evidence that temperature increases have caused a rise in global sea level during the 20th century (GCRP 2014 citing Parris et al. 2012, UN 2016). The change in sea level is attributed to thermal expansion of ocean water, thawing of permafrost, and the melting of mountain glaciers, ice caps, and land ice. Sea-level rise was found to be non-uniform around the world, which might result from variations in thermal expansion; exchanges of water, ocean, and atmospheric circulation; and geologic processes (IPCC 2014b, UN 2016). Higher sea levels cause greater coastal erosion; changes in sediment transport and tidal flows; landward migration of barrier shorelines; fragmentation of islands; and saltwater intrusion into aquifers, croplands, and estuaries (GCRP 2014 citing Burkett and Davidson 2012, CCSP 2009, IPCC 2007a, Irish et al. 2010, and Rotzoll and Fletcher 2013, Nicholls and Cazenave 2010). Furthermore, regional sea-level rise has contributed to amplified storm-surge impacts and an increased risk of flooding in certain low-lying areas, affecting the growing populations along the coasts (GCRP 2014). In many locations, the cost of rebuilding beaches and dunes is increasing as supplies near project sites are depleted (IPCC 2014b).

Tebaldi et al. (2012) (as cited in IPCC 2014b) estimated projected changes in coastal flooding during storm events at 55 locations along the U.S. coastline. The study used a semi-empirical approach (i.e., a relationship derived between observed global annual temperature and observed annual sea level, driven by projections of global annual temperature) to estimate a 0.32-meter (1.05-foot) global sea-level rise by 2050. The authors translated the global sea-level rise projection to projections of local sea-level rise at each of the coastal locations, and then used the projections of local sea-level rise to estimate the change in storm-driven water heights for historic events for a number of return periods. This study projected that most of the 55 locations will experience an increase in the frequency of extreme storm-driven waters. For a third of the locations, flooding associated with a once a century event (i.e., a storm with a 1 percent probability of occurrence in any given year) will occur more often, and statistically become a decade event (i.e., a storm with a 10 percent probability of occurrence in any given year).

Sea-level rise is expected to be one of the most damaging effects of climate change. In the 21st century, global mean sea level is expected to exceed the observed rate for the period of 1971 to 2010 of 2.0 millimeters (0.8 inch) per year (IPCC 2014b). Sea-level rise will expand floodplain areas and place more individuals in high-hazard zones; coastal communities could face increased flooding and erosion. Coastal systems and low-lying areas are expected to increasingly experience submergence, flooding, and erosion of beaches, sand dunes, and cliffs (IPCC 2014b). Coastal squeeze, which occurs when an eroding shoreline approaches hard, immobile structures, is expected to accelerate with a rising sea level.

Displacement of coastal populations due to sea-level rise, flooding, and increased intensity and frequency of storms remains a concern. Furthermore, the loss or degradation of coastal ecosystems has a direct impact on societies that depend on coastal-related goods and services such as freshwater and fisheries and has the potential to impact hundreds of millions of people.

Acidification and Hypoxia

Oceans absorb approximately 25 percent of human-caused CO_2 annually, resulting in a 30 percent increase in acidification since pre-industrial times (GCRP 2014 citing NRC 2010, Sabine et al. 2004, and Feely et al. 2009). There is very *high confidence* that coastal areas experience considerable temporal and spatial variability in seawater pH compared to the open ocean due to additional natural and human influences (IPCC 2014b). Increased CO_2 uptake in the oceans makes it more difficult for organisms to form and maintain calcium carbonate shells and skeletal structures; increases erosion and bleaching of coral reefs and their biodiversity; and reduces growth and survival of shellfish stocks globally (GCRP 2014 citing Tribollet et al. 2009, Wisshak et al. 2012, and Doney et al. 2009b). Changes in ocean acidity have economic impacts on aquaculture along the coast as it decreases the production of species such as oysters, mussels, and sea urchins (GCRP 2014).

There is *high confidence* that coastal acidification will continue into the 21st century but with large, uncertain regional variation (IPCC 2014b). Acidification will have significant negative consequences for coastal ecosystems, resulting in coral bleaching and mortality, decline of temperate seagrass and kelp ecosystems, and an increase of subtropical invasive species (Hooidonk et al. 2014, IPCC 2014b). Diversity, biomass, and trophic complexity of coastal communities will decrease at future pH levels (IPCC 2014b citing Barry et al. 2011 and Kroeker et al. 2013).

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. Specifically, waters with oxygen concentrations below 60 µmoles/kg are considered hypoxic (IPCC 2014b citing Deutsch et al. 2011). Oxygen minimum zones (OMZ) have been growing over the past half-decade and are projected to continue expanding to temperate and sub-polar regions with future warming (IPCC 2014b). Research has found that the ability of marine organisms to survive in hypoxic conditions is further strained by warming ocean temperatures. Marine benthic organisms (i.e., organisms that live on or near the ocean floor) 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; *see* Section 5.6 for additional information on ocean acidification).

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 ocean salinity levels affects the density of water, which in turn impacts factors such as the availability of local drinking water and, potentially, global ocean circulation patterns. Although the globally averaged salinity change is small, changes in regional basins have been significant. Salinity in ocean waters has decreased in some tropical and higher latitudes due to a higher precipitation-to-evaporation ratio and sea-ice melt (IPCC 2014b citing Durack et al. 2012). 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. 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 minimal changes (Durack and Wijffels 2010). However, these are general trends and vary somewhat, both across the large bodies of water and below thermocline[46] levels. Changes in salinity are likely to affect ocean density, structure, and circulation in the future. Ocean circulation is primarily driven by changes in seawater density, which is driven by temperature and salinity. Colder and more saline water (such as the waters found in the North Atlantic) is denser and sinks into ocean depths, resulting in downwelling.[47] Projected changes in salinity will likely influence ocean circulations, especially at higher latitudes where salinity is a more active variable.

Productivity

Net primary production (NPP) refers to the net flux of carbon from the atmosphere into organic matter over a given time period.[48] Ocean systems provide approximately half of global NPP. NPP is influenced by physical and chemical gradients at the water surface, light, and nutrient availability. A changing climate alters the mixed layer depth, cloudiness, and sea-ice extent, thus altering NPP. Open-ocean NPP is projected to reduce globally, with the magnitude of the reduction varying depending on projection scenario (IPCC 2014b). 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. Lower chlorophyll concentrations at warmer sea surface temperatures in nutrient-poor waters indicate declining phytoplankton stocks, particularly in the North and South Pacific and North and South Atlantic (IPCC 2014b). According to research by Arrigo and van Dijken, longer growing seasons and more sea-ice free days could have increased NPP in Arctic waters in the past decade and are expected to increase through the next century (IPCC 2014b citing Arrigo and van Dijken 2011).

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[46] A thermocline is a transitional layer between water at the surface (also known as the mixed layer) and deep water. The definition of these layers is based on water temperature. In the thermocline, the temperature decreases rapidly from the mixed layer to the deep water (NOAA 2012a).

[47] Downwelling, or the sinking of water from the surface, is an important part of the ocean circulation process that brings oxygen-rich water to the deep sea.

[48] Net primary production is estimated as the amount of carbon synthesized via photosynthesis minus the amount of carbon lost via cellular respiration.

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.

5.5.2.3.3 Adaptation

Projected impacts from climate change will require some level of adaptation to address impacts on affected marine, coastal, and low-lying regions. Adaptation for sea-level rise falls mostly into three major categories: retreat, accommodate, and protect (IPCC 2014b citing Nicholls 2011), which are widely used around the world (IPCC 2014b citing Boateng 2010 and Linham and Nicholls 2012). Retreating allows the impacts of sea-level rise to occur unobstructed, while inhabitants pull back from inundated coastlines. Accommodation is achieved by increasing the flexibility of infrastructure and adjusting the use of coastal zones where impact is most likely (IPCC 2014b). Protection is the creation of barriers against sea intrusion through the use of replenished beaches and seawalls. Ecosystem-based protection strategies, which include the protection and restoration of relevant coastal natural systems (IPCC 2014b citing Schmitt et al. 2013), oyster reefs (IPCC 2014b citing Beck et al. 2011), and salt marshes (IPCC 2014b citing Barbier et al. 2011), are increasingly attracting attention (IPCC 2014b citing Munroe et al. 2011).

For the 21st century, the benefits of adaptation initiatives for coastal and ocean systems are larger than the social and economic costs of inaction (IPCC 2014b). The cost of inaction is estimated to be 4–10 times greater than the costs associated with preventative hazard mitigation (GCRP 2014 citing Neumann et al. 2010 and Multihazard Mitigation Council 2005), but the costs vary strongly between and within regions and countries (IPCC 2014b). Low-lying developing countries such as Bangladesh or Vietnam and small island states will face higher adaptation costs that could amount to several percentage points of GDP (IPCC 2014b).

Progress has been made in the United States in the past few years in terms of coastal adaptation, science, and practice, but most coastal managers are still building their capacities for adaptation (GCRP 2014 citing NRC 2010, Carrier et al. 2012, Moser 2009, and Poulter et al. 2009). Some examples of coastal adaptation include (1) integrating natural landscape features with built infrastructure (green and gray infrastructure[49]) to reduce storm water runoff and wave attack; (2) constructing seawalls around wastewater treatment plants and pump stations; (3) pumping effluent to higher elevations as sea levels rise; (4) pumping freshwater into coastal aquifers to mitigate salt water infiltration; (5) developing flood-proof infrastructure; (6) relocation of large coastal infrastructure away from the coast; and (6) relocation of communities away from high-hazard areas (GCRP 2014). Some examples of ocean adaptation include (1) reducing overfishing, establishing protected areas, and conserving habitat to increase resilience; (2) culturing acid-resistant strains of shellfish; (3) oyster reef and mangrove restoration; (4) coral reef restoration and protection; and (5) developing alternative livelihood options for marine food-producing sectors (GCRP 2014).

5.5.2.4 Food, Fiber, and Forest Products

Climate change is affecting food, feed, fiber, forest products, and food security around the world. Increases in atmospheric CO_2, rising temperatures, and altered precipitation patterns will affect both

[49] Green infrastructure refers to sustainable pollution reducing practices that also provide other ecosystem services (e.g., permeable pavements, green roofs). Gray infrastructure refers to traditional practices for stormwater management and wastewater treatment, such as pipes and sewers.

agricultural and forest systems (Walthall et al. 2012, GCRP 2014, IPCC 2014, USDA 2015, USFS 2016). For example, climate change is predicted to affect a wide range of ecosystem processes, including maintenance of soil quality and regulation of water quality and quantity (GCRP 2014, USDA 2015). Changes in these and other ecosystem services will exacerbate stresses on agricultural plants and animals and forests (Walthall et al. 2012, GCRP 2014). Additionally, increased frequency and intensity of extreme weather events is expected to negatively influence agricultural and forest productivity and increase the vulnerability of agriculture and forests to climate risks (Walthall et al. 2012, GCRP 2014, IPCC 2014, USDA 2015, USFS 2016). Overall projections for crop and livestock production systems indicate that climate change effects over the next 25 years will be mixed (IPCC 2014, Walthall et al. 2012), although most predictions for climate change effects on crop yields by 2050 are negative (Nelson et al. 2014, IPCC 2014, Müller and Robertson 2014). Forests are becoming more vulnerable to ecosystem changes and tree mortality due to fire, insect infestation, drought, disease outbreaks, and extreme weather events (Joyce et al. 2014, IPCC 2014b, USFS 2016). Additionally, climate change and current trends in land use and forest management are expected to decrease the current forest CO_2 uptake rate (Joyce et al. 2014, USFS 2016).

Over the past 150 years, landowners and forest managers have demonstrated an impressive capacity to adapt to a diversity of growing conditions amid dynamic social and economic changes (Walthall et al. 2012, Joyce et al. 2014). However, current adaptation technologies are predicted to be insufficient to buffer future impacts of climate change resulting in significant impacts on domestic producers, consumers, or both (GCRP 2014). Forest management responses to climate change will be influenced by the changing nature of private forestland ownership, globalization of forestry markets, emerging markets for bioenergy, and climate change policy. Agricultural plants and animals and managed forests will strongly depend on the responses taken by humans to moderate the effects of climate change (Walthall et al. 2012, Joyce et al. 2014).

5.5.2.4.1 Summary

Climate disruptions to agricultural production have increased over the past 40 years and are projected to further increase over the next 25 years. Climate change is also increasing tree mortality and forest ecosystem vulnerability due to fire, insect infestations, drought, disease outbreaks, and extreme weather events. As critical thresholds are already being exceeded, increased incidences of weather extremes will result in larger productivity losses in crops, livestock, and forests. Increases in temperatures and changes in precipitation patterns are changing the nutritional quality of pastures and grazelands, stressing animals and decreasing livestock productivity. Increases in ocean temperatures are resulting in many marine fish species migrating to deeper and/or colder water and are adding additional stress to already strained coral reefs.

Many regions will experience declines in production of crops, livestock, and forests due to increases in weeds, diseases, insect pests, and other climate change induced stresses, although currently there are no models to accurately predict these impacts. Climate change effects on food, including yields, food processing, storage, and transportation, will affect food prices and food security globally, with impacts likely having the greatest effects on individuals in developing countries.

5.5.2.4.2 Observations and Projections of Climate Impacts

<u>Agriculture and Croplands</u>

As agriculture is central to the livelihoods of many people, especially in developing countries, climate change poses a significant challenge to the agricultural community globally (IPCC 2014b). This is due to agriculture's dependence on climate and the complex role of agriculture in social and economic systems at rural and national levels (GCRP 2014). As plant responses to climate change are dependent on complex interactions between CO_2, temperature, solar radiation, and precipitation, climate change is currently having both positive and negative impacts on crop and food production, although negative impacts are more common in most regions (IPCC 2014b). Future impacts are predicted to be both positive and negative (GCRP 2014, USDA 2015), although the majority of models indicate that yields of major crops will be negatively affected by climate change (Nelson et al. 2014, Müller and Robertson 2014). Specific climate impacts on agriculture will vary based on the species, location, timing, and current productivity of agricultural systems (including crops, livestock, and fish) at local, national, and global scales (GCRP 2014, USDA 2015).

Climate change is predicted to cause multiple abiotic ("non-living") stressors (such as temperature, moisture, extreme weather events), and biotic ("living") stressors (such as disease, pathogens, weeds and insects) on crop production. Changes in precipitation patterns are predicted to result in changes in timing of rains (which can affect when to plant crops), intensity of rains, floods, and droughts (Thornton et al. 2014, IPCC 2014b, GCRP 2014). Temperature changes (including mean temperature and temperature extremes) affect multiple plant processes including growth, production of seeds, fruits and fibers, and yield (IPCC 2014b, GCRP 2014). Additionally, weather extremes including heat, severe drought, and heavy precipitation are expected to increase (GCRP 2014 citing Peterson et al. 2012) and studies suggest increased average temperatures and drier conditions will amplify future drought severity and temperature extremes (GCRP 2014 citing IPCC 2007a, Alexander et al. 2006, and Karl et al. 2012; USDA 2015).

Crop yields are both positively and negatively impacted by changes in temperature, depending on the crop species as well as the timing and amount of temperature change (including both mean and extreme temperatures). All plants have specific temperature tolerances, and as temperatures increase above these tolerances, crop production areas could have to shift or plant growth and yields will likely be reduced (GCRP 2014, IPCC 2014b). For example, wheat plants exposed to high temperatures have a reduced time to maturation (IPCC 2014b citing Iqbal et al. 2009), reduced grain setting (if high temperatures occur during flowering) (IPCC 2014b citing Moriondo et al. 2011), and experience increased water stress throughout the growing season (IPCC 2014b citing Lobell et al. 2012). Temperature is of particular importance to crop production during reproduction (including pollination) and fruit/grain setting. Exposure to high nighttime and overall temperatures during this period have been shown to result in lower productivity and quality, greatly reduced crop yields, and increased risk of total crop failure (GCRP 2014 citing Walthall et al. 2012; GCRP 2014; Teixeira et al. 2013). For example, nighttime temperatures of 32°C (89.6°F) result in a 90 percent reduction of rice yields compared to night time temperatures of 27°C (80.6°F) (Thornton et al. 2014 citing Mohammed and Tarpley 2009). In particular, temperate and sub-tropical agricultural areas are predicted to experience substantial crop yield losses due to extreme temperature episodes (Teixeira et al. 2013). Perennial specialty crops with winter chilling requirements (including fruit and nut trees and grape vines) also show reduced yields if their chilling requirements are not met (GCRP 2014 citing Luedeling 2012).

Precipitation extremes are predicted to become increasingly intense, and rainfall variability is expected to increase resulting in an increase of floods and droughts (GCRP 2014). Increased frequency of extreme precipitation events is expected to reduce yields by exacerbating soil degradation and loss (GCRP 2014). Increased rainfall intensity will escalate soil erosion (GCRP 2014 citing Kunkel et al. 2013g, Mass et al. 2011) as will reduced crop biomass resulting in fewer crop residues available to stabilize soil surfaces during winter months (GCRP 2014 citing O'Neal et al. 2005 and Wischmeier et al. 1978). Shifting precipitation patterns will change timing of planting and growing seasons as well as contribute to dry spells and sustained droughts that will likely reduce yields (Thornton et al. 2014).

Climate change has the potential to increase the impacts of disease, pathogens, insects, and weed species in agricultural crops. Currently, weed growth is the largest biotic cause of crop yield loss globally (34 percent), followed by insects (18 percent) then disease (16 percent) (GCRP 2014 citing Oerke et al. 2006). While elevated CO_2 levels and temperatures have been shown to increase both crop and weed growth, several weed species have been shown to outcompete crops under these conditions, likely resulting in further reduced crop yields (GCRP 2014 citing Ziska 2001, 2003, 2010). As temperatures and CO_2 levels continue to rise, costs for weed control[50]—including herbicides—are expected to increase (Ziska 2014, GCRP 2014 citing Koleva et al. 2009).

In terms of insects and diseases, earlier spring and warmer winter conditions are expected to increase the survival and proliferation of disease-causing agents and parasites (GCRP 2014). Warmer winter temperatures increase insect winter survival rates, and higher summer temperatures increase reproductive rates, allowing for more insect generations in a year (GCRP 2014 citing Porter et al. 1991). Furthermore, changing climate and trade patterns are expected to increase the risk and sources of invasive species (GCRP 2014 citing Bradley et al. 2012). However, due to the lack of models, it is not currently possible to quantitatively estimate climate change induced impacts of diseases, pathogens, insects, or weed species on agricultural plants (GCRP 2014, Nelson et al. 2014).

Interestingly, increases in temperature, CO_2 concentration and solar radiation have been predicted to increase growth rates of some plants (GCRP 2014). However, effects vary by plant species and are also dependent on other factors, such as adequate water and soil nutrients. For example, if soil nutrients and water are not sufficient to support increased growth rates, smaller plants with lower production values will be produced (GCRP 2014). Additionally, weed growth is also predicted to increase under these conditions, further dampening any potential yield gains from increased growth rates (GCRP 2014).

Overall, climate change is predicted to have mixed, although mostly negative, effects on crop yields, depending on the crop species and location. Studies comparing projections for different regions or crops have identified South Asia and Southern Africa as two regions that are likely to suffer the most negative impacts on important crops (IPCC 2014b citing Lobell et al. 2008) with Knox et al. (2012) estimating an expected 8 percent negative yield in both areas by 2050 averaged over multiple crops (IPCC 2014b citing Knox et al. 2012). Müller and Robertson (2014) used two agricultural models, Decision Support System for Agrotechnology Transfer (DSSAT)[51] and Lund-Potsdam-Jena managed Land (LPJmL)[52], under the high-end emissions scenario (RCP8.5) and two general circulation models, HadGEM2- and IPSL-CM5ALR, to determine yield projections in 2050. Projections were conducted for the five crops that are simulated by both models: wheat, maize, rice, soybean, and groundnut. Under all analyzed scenarios, with the exception of temperature limited mountains and high latitude areas, climate change led to decreases in agricultural productivity, with crop yields decreasing by 9.9 to 37.6 percent on a global scale by 2050 as compared to 2000 (Müller and Robertson 2014). In general, climate impacts on yields had similar distributions between crop models and climate scenarios, but spatial patterns of impacts differed significantly with some areas showing increased yield and others showing decreased yield (Müller and Robertson 2014). For example, rainfed wheat productivity showed

[50] Currently approximately US$11 billion a year.

[51] DSSAT is a framework for crop models that uses daily weather information and a soil module that keeps track of hydrology and nutrient cycles based on consideration of a variety of soil characteristics. Other models were used to input specifics for crops: CERES models for rice (Oryza sativa), wheat (Triticum spp.), and maize (Zea mays) and the CROPGRO models for soybeans (Glycine max), and groundnuts (Arachis hypogaea).

[52] LPJmL is a global dynamic vegetation, hydrology, and crop growth model that simulates yields of the 12 most important crops globally: temperate and tropical cereals, roots and tubers, maize, rice, pulses, soybeans, oil crops and sugarcane.

increases in the eastern United States (including Michigan and Ohio), Estonia, Latvia, and the western regions of Russia using the DSSAT model, but the same areas showed decreases in productivity using the LPJmL model (Müller and Robertson 2014).

Using the same combination of agricultural and general circulation models and the same emissions scenario (RCP8.5), Nelson et al. (2014) determined the annual effects of climate change on the yields of the major commodity groups (coarse grains, rice, oil seeds, sugar, and wheat) in five countries (Brazil, Canada, China, India, and the United States) compared to no climate change from 2005 to 2050. The climate effects are almost uniformly negative, with the largest decreases in yield most commonly found in crops grown in India and Brazil (Nelson et al. 2014). Sugar was the only crop showing moderate yield increases in all countries (except India) under multiple model combinations (Nelson et al. 2014). In the United States, projections suggest substantial decreases in yield for most major agricultural crops by 2100, assuming no global GHG mitigation (EPA 2015g). All crops[53] (except hay) are projected to experience yield decreases (3 to 39 percent) under irrigated conditions whereas projections for rainfed crops suggest greater variability in yield, ranging from a projected 18 percent increase in yield for wheat and sorghum and a 65 percent decrease in yield for hay. With global GHG mitigation, projections[54] suggest substantially improved yields for all crops (except hay and sorghum) under both rainfed and irrigated conditions compared to the scenario without global GHG mitigation (EPA 2015g).

Livestock

Although there is not as much work published on livestock production, climate change is predicted to have multiple effects on animal production. These effects include animal nutrition (production, availability, and price of feed-grains as well as production and quality of pasture and forage crops) and overall animal wellbeing (animal health, growth, and reproduction and distribution of animal diseases and pests) (GCRP 2014 citing Rötter et al. 1999). Overall, current predictions are that climate change will negatively impact livestock on almost all the continents (IPCC 2014b).

In many livestock systems, one of the major climate change impacts on animals is changes in feed quantity and quality (Thornton et al. 2014). In particular climate change is predicted to impact pastures and animal feed through changes in temperature and rainfall (including variability and amount); CO_2 concentrations; extreme weather events; and changes in diseases, pathogens, weeds, and insect species (IPCC 2014b, Thornton et al. 2014). For example, in North America, warming is predicted to both lengthen the growing season and decrease forage quality with additional variation due to changes in rainfall patterns (IPCC 2014b citing Craine et al. 2010 and Izaurralde et al. 2011; GCRP 2011). Species composition in both temperate and tropical grassland is a key determinate of livestock productivity. Climate change is predicted to impact the dynamics and balance of grassland species, including plant competition, perennial growth habits, and seasonal productivity, which could also affect livestock productivity (Thornton et al. 2014, IPCC 2014b). Given the complex interactions between climate and non-climate drivers on pastures and forageland, it is currently difficult to predict long-term impacts of climate change on these lands (IPCC 2014b, Thornton et al. 2014).

In terms of direct impacts on animals, there is high confidence that high temperatures will have negative effects on animal feeding and growth rates (IPCC 2014b citing André et al. 2011, Renaudeau et al. 2011). In general, livestock have comfort zones between 10˚C (50˚F) and 30˚C (86˚F) (Thornton et al. 2014) and

[53] Crops modeled include: cotton, corn, soybean, sorghum, rice, hay, potato, wheat and barley.

[54] Mitigation scenario suggests a greenhouse gas radiative forcing of 3.6 W/m^2 by 2100; while the business as usual (i.e., reference) scenario estimates a greenhouse gas radiative forcing of 9.8 W/m^2 by 2100.

can tolerate deviations in core body temperatures of up to 4˚F. Deviations in excess of 4 to 5°F cause significant reductions in productive performance while deviations in the range of 9 to 12°F often result in death (GCRP 2014 citing Gaughan et al. 2009). For example, when exposed to temperatures above 30°C (86˚F) animals reduce their feed intake 3 to 5 percent per additional degree of temperature (Thornton et al. 2014 citing NRC 1981), which can result in reduced rates of meat, milk, and egg production (GCRP 2014 citing Mader 2012). While livestock production systems that provide partial or total shelter can reduce heat stress, management and energy costs associated with such structures are predicted to increase with increasing temperatures and decreasing water availability (GCRP 2014). Changes in rainfall distribution are also expected to exacerbate existing challenges of supplying adequate water to livestock (IPCC 2014b).

Changes in climate variability, including rainfall distribution, regional warming patterns, and extreme weather events are predicted to impact the prevalence and distribution of livestock host and pathogen systems (GCRP 2014, Thornton et al. 2014, IPCC 2014b). For example, disease outbreaks of Rift Valley fever and blue-tongue in east Africa have followed combinations of high rainfall preceded by drought (Thornton et al. 2014 citing Baylis and Githeko 2006). Rift Valley fever could continue to spread northward due to rising temperatures and the increased winter survival of pathogens and hosts (IPCC 2014b citing Lancelot et al. 2008). Other diseases also sensitive to moisture and temperature could also spread under changing climatic conditions. These include anthrax, blackleg, and hemorrhagic septicemia, which cause increased incidence of ketosis, mastitis, and lameness in dairy cows (GCRP 2014 citing Gaughan et al. 2009 and Baylis and Githeko 2006).

<u>Fisheries</u>

Climate change is affecting aquatic ecosystems, including marine and freshwater fisheries (IPCC 2014b, Groffman et al. 2014). Fisheries are important contributors to food security and 90 percent of individuals involved in the sector are employed in small-scale fisheries, many of whom are in developing countries (IPCC 2014b citing Cochrane et al. 2011). Climate change impacts on marine fisheries have primarily been linked to increasing temperatures (including both mean and extreme temperatures), but are also affected by increasing CO_2 concentrations (IPCC 2014b). Fisheries can also be impacted by overfishing, pollution, land or habitat change, and climate variability, making it difficult to determine which effects are directly attributable to climate change and which are due to other factors (IPCC 2014b).

Climate change induced increases in ocean temperatures have resulted in shifts of many fish species to cooler and/or deeper water (IPCC 2014b). For example, current studies of the northeast Atlantic have shown that rising sea temperatures are resulting in a poleward shift in the distribution of fish, increasing abundance to the north and decreasing abundance to the south (IPCC 2014b citing Perry et al. 2005, Brander 2007, Cheung et al. 2010, and Cheung et al. 2013). Similar poleward trends have been seen off southeast Australia (IPCC 2014b citing Last et al. 2011). These shifts are impacting marine fisheries by changing the species composition found in marine capture fisheries where warmer water species are increasing at higher latitudes and subtropical species are decreasing in the tropics (IPCC 2014b). Barange et al. (2014) used a single general circulation model (Institute Pierre Simon Laplace Global Climate Model (IPSL-CM4)) with the A1B climate scenario to determine mean outputs of 67 marine national exclusive economic zones (EEZs) (which yield approximately 60 percent of global fish catches) from the present to 2050. The models predicted an average increase in the global fisheries production potential of 3.4 percent by 2050, with ecosystems in higher latitudes experiencing production increases and those in lower latitudes experiencing decreases (Barange et al. 2014). For example, the Nordic Sea, the Gulf of Guinea, and the Kuroshio Current region are predicted to have the largest average increase in fish catch potential (29.3, 29.3 and 21.3 percent respectively), while the Canary Current and the northwestern American shelf are predicted to have the largest average decreases (-14.6 and -13.2

percent, respectively) (Barange et al. 2014). Reductions in catch potential are predicted to have the greatest negative impacts for countries most nutritionally and economically dependent on fisheries, including those in south and southeast Asia, southwest Africa, Peru, and some tropical small-island developing states (Barange et al. 2014, IPCC 2014b).

Warmer temperatures and temperature fluxes negatively affect coral reefs and reef ecosystems. Coral reef ecosystems provide food and other resources to more than 500 million people annually at an estimated value of US$5 billion or more (IPCC 2014b citing Hoegh-Guldberg 2011 and Munday et al. 2008). Currently more than 60 percent of coral reefs are considered to be under immediate threat of danger due to local threats (such as pollution and overfishing) and projected increases in sea temperature and heat stress will very likely irreversibly degrade reefs even further (IPCC 2014b). Coral bleaching and other reef challenges have also resulted in a loss of fish species that feed on coral-associated invertebrates, and fish and invertebrate species associated with reefs in many important tropical coastal fisheries are very likely to be reduced (IPCC 2014b). In the United States, extensive loss of shallow corals is projected for major U.S. reef locations (Hawaii, South Florida, and Puerto Rico) by 2050 if global GHG mitigation does not occur (EPA 2015g). Even under global mitigation scenarios,[55] while Hawaiian coral reef loss is projected to be delayed, only minor benefits are projected for South Florida and Puerto Rico, as those reefs are currently close to critical threshold of loss. Mitigation is also projected to result in approximately US$22 billion of recreational benefits for all three regions through 2100 compared to the baseline scenario (EPA 2015g).

There are fewer data available on climate change impacts on fisheries in freshwater systems, with current changes and predictions showing mixed results (IPCC 2014b, Comte et al. 2013a). Comte et al. (2013a) conducted a meta-analysis of published literature reporting observed and predicted effects of climate change on the distribution of freshwater fish. Despite large data gaps and a geographic bias towards the northern hemisphere and the temperate regions of the Nearctic and Palaearctic realms, the authors found that freshwater species could be severely affected by current and future climate change resulting in mixed effects. For example, temperature increases are estimated to cause a loss of 11 to 22 percent of suitable stream length for bull trout in central Idaho, while resulting in a gain of small patches of habitat for rainbow trout (Comte et al. 2013b citing Isaak et al. 2010). Cold- and cool-freshwater fish are expected to be impacted by warming temperatures, which could result in local extinctions, contractions, or shifts in habitat, whereas warm-water species could benefit from warmer water, depending on the species, the local habitat, and non-climate stressors (Comte et al. 2013a). Projections suggest that unmitigated climate change will warm waters and change stream flow in the United States, likely altering freshwater fisheries across the country and resulting in the replacement of coldwater species with less economically valuable species, especially in the Mountain West and Appalachia, by 2100 (EPA 2015g). Specifically, coldwater fisheries habitat is projected to decline 62 percent nationally through 2100. In contrast, the global GHG mitigation scenario projects a 12 percent decline in coldwater fisheries habitat and avoids a loss of US$380 million to US$1.5 billion in total recreational fishing through 2100 compared to the unmitigated scenario (EPA 2015g).

Similar to marine fisheries, changes in productivity in freshwater fisheries can be impacted by both climate and non-climate stressors, making it difficult to determine which effects are directly attributable to climate change (IPCC 2014b). For example, studies on Lake Tanganyika in east Africa have conflicting results, with one study showing a 30 percent reduction in lake productivity due to climate change (IPCC 2014b citing O'Reilly et al. 2003) and another indicating that the reduction is due to non-climate related

[55] Mitigation scenario suggests a greenhouse gas radiative forcing of 3.6 W/m^2 by 2100; while business as usual scenario estimates a greenhouse gas radiative forcing of 9.8 W/m^2 by 2100.

factors, such as overfishing (IPCC 2014b citing Sarvala et al. 2006). Accurate predictions of future effects of climate change on freshwater fisheries are currently limited by incomplete data and limited modeling capabilities (Comte et al. 2013a, IPCC 2014b).

Forests

Forests and climate change have strong interactions with each other. Air temperature, solar radiation, rainfall, and atmospheric CO_2 all can drive forest productivity, and forests control climate through carbon sequestration and release and evapotranspiration (i.e., the evaporation of water from soil and land, and transpiration from vegetation) (IPCC 2014b citing Arneth et al. 2010, Pan et al. 2011, and Pielke et al. 2011). As such, it is difficult to predict climate change impacts on forest productivity. For example, some end-of-century projections assuming no GHG mitigation suggest increases in forest productivity in the United States could vary between 0 to 4.5 percent dependent on climate model and forest type (EPA 2015g).[56]

Currently, tree mortality is increasing globally due in part to high temperatures and drought (IPCC 2014b). There is *medium confidence* that this increased mortality and forest dieback (high mortality rates at a regional scale) will continue in many regions around the globe through 2100 (IPCC 2014b). For example, in western North America, long-term increasing tree mortality in boreal and temperate forests has been associated with high temperatures and drought (IPCC 2014b citing van Mantgem et al. 2009 and Peng et al. 2011), and increased tree mortality has been detected after drought in multiple tropical forests and Europe (IPCC citing Kraft et al. 2010, Phillips et al. 2010, and Carnicer et al. 2011). Forest dieback has been observed in multiple types of forests in western North America, Australia, and southern Europe (IPCC citing Raffa et al. 2008, Carnicer et al. 2011, and Anderegg et al. 2013) and in some cases in combination with insect infestations (IPCC 2014b citing Hogg et al. 2008, Michaelian et al. 2011, and Raffa et al. 2008). However, due to the lack of models and limited long-term studies, projections of global tree mortality are currently highly uncertain (IPCC 2014b citing McDowell et al. 2011).

Other climate change induced direct and indirect effects, such as changes in the distribution and abundance of insects and pathogens, fire, changes in precipitation patterns, invasive species, and extreme weather events (e.g., high winds, ice storms, hurricanes, and landslides) are also affecting forests (Thornton et al. 2014, IPCC 2014b, GCRP 2014, IPCC 2014b citing Allen et al. 2010a). Warmer winter temperatures have resulted in increased insect populations, and projected temperature increases are expected to facilitate their expansion poleward and in altitude, contributing to or causing tree mortality (IPCC 2014b citing Bentz et al. 2010). For example, the USDA Forest Service reports that approximately 81 million acres of the nation's forests are at risk of insects and diseases (Krist et al. 2014). Heat waves and drought are contributing to increased wildfires in forests and are resulting in predictions of increased fire risk. For example, in the lower 48 states of the United States, there has been an 84 percent increase in wildfires since 1990 (EPA 2014f), and approximately 58 million acres of National Forest System lands are at risk of intense wildfire (Krist et al. 2014). Without GHG mitigation, a dramatic increase in the area burned by wildfire is projected in the contiguous United States through 2100, especially in the West (EPA 2015g). Increased fire risk, a longer fire season, and more frequent, severe fires due to heat waves and drought are also predicted in the Mediterranean region (IPCC 2014b citing Duguy et al. 2013). Tracking and attributing disturbance and corresponding mortality is a challenge; however, with satellite imagery severity can be mapped as a percent change in satellite-derived Disturbance Index (Joyce et al. 2014 citing Mildrexler et al. 2009).

[56] It is important to note that these projections do not consider impacts associated with wildfire, pests, or disease.

Tree species are predicted to shift their geographic distributions to track figure climate change (Zhu et al. 2014, USFS 2016). For example, many projections are for poleward expansions of forests into tundra regions, and species shift towards temperate plants, and there is *medium confidence* that temperate tree species are migrating poleward and to higher altitudes (IPCC 2014b). To determine if shifting is already occurring, Zhu et al. (2014) modeled juvenile and adults from 65 tree species across climates in the eastern U.S. using species abundance data from the Forest Inventory and Analysis (FIA) program and climate data from the Parameter-elevation Regression on Independent Slopes Model (PRISM). The authors found that juvenile tree distribution did not appear to follow a northern migration pattern, but it instead followed patterns of rapid turnover in warm and wet climates (likely due to longer growing seasons resulting in faster maturation and rapid thinning) (Zhu et al. 2014). The authors concluded that at biogeographic scales, U.S. forests are responding to climate change with faster turnover rates, but not yet northward migration (Zhu et al. 2014).

Reduced Sequestration

While there is currently *high confidence* that forests are serving as a net carbon sink globally, it is unclear if this trend will continue (IPCC 2014b). Excess carbon sequestered by intact and regrowing forests appears to have stabilized in recent years (IPCC 2014b citing Canadell et al. 2007 and Pan et al. 2011). Warming, changes in precipitation, pest outbreaks, and current social trends in land use and forest management are projected to impact the rate of CO_2 uptake in the future (Joyce et al. 2014, IPCC 2014 citing Allen et al. 2010a), making it difficult to predict whether forests will continue to serve as net carbon sinks in the long term (IPCC 2014b). Without global GHG mitigation, end-of-century projections for the contiguous United States suggest terrestrial carbon sequestration (including forests, grasslands and shrublands) could vary substantially across regions from an increase of almost 20 percent to a decrease of almost 15 percent, somewhat dependent on whether the climate model suggests a wetter or drier future (EPA 2015g).

Food Security and Risks to Vulnerable Populations

Climate change impacts on food security and food systems are predicted to be widespread, complex, geographically and temporally variable, and greatly influenced by socioeconomic conditions (IPCC 2014b citing Vermeulen et al. 2012). Food security comprises four key components: availability, stability, access, and utilization of food (GCRP 2014 citing FAO 2001), all of which are closely tied to poverty (IPCC 2014b). Food security is affected by variety of supply and demand-side pressures, including economic conditions, globalization of markets, safety and quality of food, land use change, demographic change, disease, and poverty (GCRP 2014 citing Ericksen et al. 2009 and Misselhorn et al. 2012). While there is a limited quantitative understanding of how non-production aspects of food security will be affected by climate change, it is likely that they will also be affected by climate change (IPCC 2014b).

Projected rising temperatures, changing weather patterns, and increases in the frequency of extreme weather events will affect food security by potentially altering agricultural yields, post-harvest processing, food and crop storage, transportation, retailing, and food prices (GCRP 2014). For example, 10 economic models (using 2 agricultural models, 2 general circulation models, and the high-end emissions scenario [RCP8.5] as their basis) currently predict that by 2050, climate change will increase the aggregate price of the 5 major commodity groups (coarse grains, rice, oil seeds, sugar, and wheat) by 3 to 78.9 percent (Nelson et al. 2014). Similarly, von Lampe et al. (2014) used the identical suite of 10 economic models (using 2 agricultural models, 2 general circulation models, and the high end-emissions scenario [RCP8.5]) to model food security and food prices in 2050 under alternate socio-economic, climate change, and bioenergy scenarios. While each of the models produced different results, the authors found that in general, climate change will result in reduced per capita calorie availability around the world in 2050 compared to scenarios with no climate change, with the largest decline in India at 11 percent (von Lampe et al. 2014). Production of biofuels was found to have a much smaller impact on agricultural prices and food security than climate change (von Lampe et al. 2014).

Of those globally who do not have enough food to eat, the vast majority of undernourished people live in developing countries (IPCC 2014b). While estimates vary as to incidence of food insecurity, sub-Saharan Africa had the highest proportion of food insecure people (39 to 59 percent depending on the study) (IPCC 2014b citing Smith et al. 2006 and FAO et al. 2012) whereas south Asia has the highest numbers of food insecure with approximately 300 million undernourished people (IPCC 2014b citing FAO et al. 2012). The United States is also experiencing food insecurity; in 2011, 14.9 percent of U.S. households did not have secure food supplies at some point during the year, and 5.7 percent of U.S. households experienced very low food security (GCRP 2014 citing Coleman-Jensen et al. 2012). As most countries import at least some of their domestic food consumed, climate change has the potential to affect not just food production but also the amount of food countries import and export. For example, using 10 economic models (described in more detail above), von Lampe et al. (2014) found that climate change could result in substantially higher net food imports in 2050 (assuming no changes in trade policies), with some regions being more affected than others, as compared to scenarios with no climate change. For example, in 9 out of 10 models, India was shown to increase its net imports of the five major commodity groups (described above), whereas most models showed Canada and Brazil increasing net exports of these groups (von Lampe et al. 2014).

5.5.2.4.3 Adaptation

Agricultural producers have always had to adapt to their environment to be economically successful. Recent changes in climate, however, threaten to outpace the current adaptation rate and create challenges for the agricultural sector and associated socioeconomic systems (GCRP 2014, IPCC 2014b). Economic literature indicates that in the short term, producers will continue current adaptation practices for weather changes and shocks (e.g., by changing timing of field operations, shifts in crops grown, changing tillage/irrigation practices) (GCRP 2014 citing Antle et al. 2004). In the long-term, however, current adaptation technologies will likely prove insufficient to buffer the impacts of climate change (GCRP 2014). However, practices associated with sustainable agriculture, such as diversifying crop rotations, integrating livestock with crop production systems, improving soil quality, and minimizing off-farm flows of nutrients and pesticides can increase resiliency to climate change (GCRP 2014 citing Easterling 2010, Lin 2011, Tomich et al. 2011, and Wall and Smit 2005). For example, in California's Central Valley, an adaptation plan was adopted that includes changes to crop mix, irrigation methods, fertilizer practices, tillage practices, and land management. This plan could prove effective to manage climate risk and is available to all agricultural regions of the United States as potential adaptation strategies (GCRP 2014 citing Jackson et al. 2009).

In terms of food security, reducing waste in the food system, making food distribution systems more resilient to climate risks, protecting food quality and safety at higher temperatures, and policies to ensure food access for disadvantaged populations during extreme events are all adaptation strategies to mitigate the effects of climate change (GCRP 2014 citing Walthall et al. 2012, Ericksen et al. 2009, Misselhorn et al. 2012, Godfray et al. 2010, and FAO 2011). Ultimately, adaptation will continue to become more difficult as physiological limits of plants and animal species are exceeded more frequently, and the productivity of crop and livestock systems becomes more variable (GCRP 2014).

In terms of forests, the emerging market for bioenergy—the use of plant-based material to produce energy—has the potential to aid in forest restoration (Joyce et al. 2014). Owner objectives, international markets for forest products, crops and energy, land value, and forestland policies all influence how forestland is managed. Flexible policies that are not encumbered with legally binding regulatory requirements can facilitate adaptive management where plants, animals, ecosystems, and people are responding to climate change (Joyce et al. 2014 citing Millar et al. 2012). Ultimately, maintaining a diversity of tree species could become increasingly important to maintain the adaptive capacity of forests (Duveneck et al. 2014).

5.5.2.5 Urban Areas

This section defines urban areas and describes the existing conditions and their potential vulnerability to climate change impacts.

Urban centers are now home to over half of the global population, and this percentage continues to increase every year (IPCC 2014b citing United Nations 2012, World Bank 2008). In the United States, approximately 80 percent of the population lives in metropolitan areas[57] (GCRP 2014). In addition to large numbers of people, urban centers also contain a great concentration of the world's economic activity, infrastructure, and assets (IPCC 2014b citing United Nations DESA Population Division 2012, World Bank 2008), many of which are aging and in need of repair or replacement (GCRP 2014). However, definitions of urban centers and their boundaries vary greatly between countries and between various pieces of academic literature. Communities between a few hundred and 20,000 inhabitants could be classified in a variety of ways, and boundaries of the urban areas vary greatly in the distance they extend from the urban core (IPCC 2014b). Definitions of urban populations frequently exclude people who live in a rural setting and commute into urban settings for work; however, they too would be impacted by the effects of climate change on their employment location (IPCC 2014b).

5.5.2.5.1 Summary

The risks of climate change to urban communities are increasing—rising sea levels, storm surges, extreme temperatures, extreme precipitation events leading to inland and coastal flooding and landslides, drought leading to increased aridity and water scarcity, and various combinations of stressors exacerbating air pollution (IPCC 2014b). These changes will have widespread impacts on the people and communities in urban areas by affecting their health, livelihoods, and belongings (such as their homes). For the global community, the IPCC suggest that these impacts will be particularly strenuous for existing vulnerable populations such as the poor, the very young and elderly, those with preexisting health conditions, and women[58] (IPCC 2014b). Climate change will have additional impacts at a larger urban scale by affecting national economics and natural ecosystems.

Climate change will profoundly affect the infrastructure that urban societies depend upon. This includes water and energy supplies, wastewater and stormwater systems, transportation, and telecommunications (IPCC 2014b). Impacts on any one of these sectors could have far reaching effects due to the interconnectedness of today's economies and the globalization of the supply chain.

The provision of social services such as healthcare, police, and education could also be affected by climate change, although less is known about these impacts. Integrating climate change considerations into these social services is necessary for their continued operation and benefit (IPCC 2014b).

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[57] Metropolitan areas include urbanized areas of 50,000 or more population, plus adjacent territory that has a high degree of social and economic integration (Office of Management and Budget 2009).

[58] Women are considered at greater risk than men as they may "face discrimination in access to labor markets, resources, finance, services and influence" (IPCC 2014b).

Wealthy nations are predominantly urbanized, and low- and middle-income nations are rapidly urbanizing. The rate of urbanization is outstripping the rate of investment in basic infrastructure and services, which is creating urban communities with high vulnerability to climate change (IPCC 2014b citing Mitlin and Satterwaite 2013). Across urban communities, there are very large differences in the extent to which economies are dependent on climate-sensitive resources, but in general, a high proportion of people most at risk of extreme weather events are located in urban areas (IPCC 2014b citing IFRC 2010, United Nations 2009, United Nations 2011).

5.5.2.5.2 Observed and Projected Climate Impacts

Many climate impacts are often assessed individually despite being highly interdependent; climate impacts on one sector will lead to secondary impacts on other sectors (GCRP 2014 citing Kirshen et al. 2008b). For example, the 2003 electric power outage in the northeastern and midwestern United States caused the shutdown of water treatment plants and pumping stations (GCRP 2014). In today's globalized economy, the supply chains are long, and impacts on a particular sector or geographic area will have wide-ranging consequences. These knock-on effects are infrequently estimated and could be unanticipated (IPCC 2014b). In the future, infrastructure could become even more interconnected and complex, which will increase the likelihood of large-scale, cascading impacts on infrastructure (GCRP 2014 citing Ellis et al. 1997).

The clustering of essential services, such as oil refineries, contributes to urban vulnerabilities because distant damages can cause widespread losses (GCRP 2014 citing Wilbanks et al. 2012). The likelihood of these impacts is increased in the United States by the aged state of the infrastructure; significant infrastructure assets have exceeded their design lives and contribute to an increasingly fragile system (GCRP 2014).

<u>Impact on Society</u>

Certain population groups are more likely to be directly impacted by climate change than others. For example, the very young and elderly are both more sensitive to heat stress; those with preexisting health issues could be more sensitive to a range of stressors; and low-income groups and women could be more sensitive due to a lack of resources and discrimination in access to support services (IPCC 2014b; Cutter et al. 2014; GCRP 2014 citing Bates and Swan 2007, NRC 2006, and Phillips et al. 2009).

The localized nature of impacts and challenges with downscaling climate data to specific locations with precision still remain (IPCC 2014b). It cannot be assumed that climate change impacts will be the same or even similar in different cities. Silver et al. (2013) demonstrate the varying impacts of climate change on two West African cities: the coastal city of Saint-Louis, Senegal, and the semi-arid Sahel city of Bobo-Dioulasso, Burkina Faso; this is a departure from the common "lumping" of West African cities into similar vulnerability categories. The paper concluded that adequately determining climate change vulnerability requires context-specific knowledge, which takes into account "geography, different climate change challenges, urban governance, and economic and cultural issues that in turn shape the economic development vulnerabilities and responses."

The process of urbanization can increase the impact of various climate stressors. For example, cities that are projected to experience rising temperatures are apt to experience temperatures even higher than projected due to the urban heat island effect (whereby the volume of paved land in urban areas absorbs and holds heat along with other causes) (IPCC 2014b). Without accounting for the urban heat island effect, using the RCP 2.6 (low emissions) scenario, it is predicted that a number of large, urban agglomerations across almost all continents will experience a temperature rise of over 1.5°C (2.7°F) (over pre-industrial levels) by mid-century scenario and up to 2.5°C (4.5°F) by the end of the century

(IPCC 2014b citing IPCC 2013b). The RCP 8.5 (high emissions) scenario suggests that, excluding urban heat island effects, urban agglomerations will experience a minimum temperature increase of 2°C (3.6°F) over pre-industrial levels by mid-century. This increased frequency of hot days will exacerbate the urban heat island effect and could lead to increased health impacts, air pollution, and increased energy demand (IPCC 2014b citing Hajat et al. 2010, Blake et al. 2011, Campbell-Lendrum and Corvalan 2007, and Lemonsu et al. 2013). However, models are beginning to show that in some locations, there could be reductions in the urban heat island effect with climate change; this is due to changes in evaporation that warm the rural surface more than the urban surface causing rural temperatures to rise, offsetting the temperature differences between the rural and urban landscape. In other areas there could be increases in the urban heat island effect (IPCC 2014b citing Früh et al. 2011, McCarthy et al. 2010, and Oleson 2012). There is also increasing evidence that cities (through an urban heat island effect) can influence larger weather trends such as precipitation and lightning (IPCC 2014b citing Grimmond 2011).

Urbanization, through increased impermeable surfaces and microclimatic changes, can also increase flooding. Huong and Pathirana (2013) used a series of models to estimate flooding in Can Tho City, Vietnam, in 2100. They found that future flooding scenarios were the most severe when they considered projected changes to sea-level rise and runoff in tandem with increased precipitation due to urban growth–driven, microclimatic change (urban heat islands can increase rainfall). They projected urban growth up to 2100 based on historical growth patterns using a land use simulation model. This was coupled with a dynamic limited-area atmospheric model that considered land surface and vegetation and provided outputs on the anticipated changes in extreme rainfall due to the urban heat island effect. Lastly, this information was run through an urban-drainage/flooding model to simulate storm sewer surcharge and surface inundation to quantify the increase in flooding hazards resulting from these changes.

By the end of the century, projections of sea-level rise range from about 26 to 122 centimeters (10 to 48 inches) (IPCC 2013c [low end]; GCRP 2014 [high end]). These rising sea levels will have far reaching effects on coastal property, populations, businesses, and ecosystems, especially in combination with storms and other natural phenomena (IPCC 2014b citing Carbognin et al. 2010, Dossou and Glehouenou-Dossou 2007, El Banna and Frihy 2009, Hanson et al. 2011). These impacts were demonstrated by several recent disasters including Hurricane Sandy in New York (IPCC 2014b). Over time, coastal communities have been expanding, placing more people and resources at risk to the impacts of sea-level rise. With about a 0.5-meter (20-inch) rise in sea levels, the population at risk of coastal flooding could more than triple while asset exposure could increase up to 10 times (IPCC 2014b citing Hanson et al. 2011).

Water Supply, Wastewater, and Sanitation

In urban areas around the world, periods of drought and heavy rainfall are expected to increase (IPCC 2014b). Drought will have many effects in urban areas including water shortages, electricity shortages (from decreased hydropower operation), water-related diseases (which could be transmitted through contaminated water), and food insecurity. These impacts will all have negative economic consequences and could lead to increases in rural to urban migration (IPCC 2014b citing Farley et al. 2011, Herrfahrdt-Pahle 2010, and Vairavamoorthy et al. 2008). Without global GHG mitigation, EPA estimates the economic cost of water shortages in the U.S. could range from US$7.7 billion to US$190 billion in 2100, depending on the modeled change in runoff and evaporation (EPA 2015g).

Already, an estimated 100 million people live in cities with less than 100 liters (26 gallons) of local, sustainable water per person per day, and by 2050 this number could increase to 1 billion people (this is an average across all climate scenarios) with increasing water scarcity (IPCC 2014b citing McDonald et al.

2011). Schewe et al. (2014) used 11 global hydrological models (GHMs) forced by five global climate models and a range of emissions scenarios to estimate future water scarcity. They concluded that with 2°C (3.6°F) of warming above current levels, about 15 percent more of the global population will face a severe decrease in water availability, and the number of people living under absolute water scarcity will increase by 40 percent when compared with the impacts of population growth alone. Arnell and Lloyd-Hughes (2014) determined that under the high (RCP8.5) emissions scenario the exposure to water resource stress could increase by approximately 1–3.5 billion people by 2050 and increase river flooding risks for 100–580 million people. Lower emissions scenarios also suggest increasing risk but at lower levels.

Changes in precipitation due to climate change could create water demand conflicts between residential, commercial, agricultural, and infrastructure use (IPCC 2014b citing Roy et al. 2012, and Tidwell et al. 2012). However, not all impacts will be negative; for example, Chicago's Metropolitan Water Reclamation District (MWRD) predicts that reduced precipitation will decrease its pumping demands because sewers will contain less rainwater in drier seasons and thus decrease operational costs (IPCC 2014b citing Hayhoe et al. 2010). Additionally, Matonse et al. (2013) used three global change models (GCMs) to develop a range of climate scenarios and found that although there will be seasonal changes in water flow, overall, New York City's water supply will continue to be highly reliable with low vulnerability to climate change.

It is projected that urban areas will be affected by changes in precipitation and water runoff and that sea-level rise will result in "saline ingress, constraints in water availability and quality, and heightened uncertainty in long-term planning and investment in water and waste water systems" (IPCC 2014b citing Fane and Turner 2010, Major et al. 2011, and Muller 2007). Additionally, urban populations could be affected by "reductions in groundwater and aquifer quality, subsidence and increased salinity intrusion" (IPCC 2014b). This problem is compounded by subsidence due to high levels of groundwater extraction (which could increase with changes in precipitation), which can damage buildings and subterranean infrastructure. These impacts are already being witnessed in Bangkok, Mexico City, and Shanghai (IPCC 2014b citing Babel et al. 2006, Romero-Lankao 2010, Jha et al. 2012, and de Sherbinin et al. 2007). The problem is more acute along coastlines where saltwater intrusion can further damage infrastructure and affect water quality (IPCC 2014b).

In developed and developing countries, stormwater systems will be increasingly overwhelmed by extreme short-duration precipitation events if they are not upgraded (IPCC 2014b citing Howard et al. 2010, Mitlin and Satterthwaite 2013, and Wong and Brown 2009). If storm drains for transportation assets are blocked, then localized flooding can cause delays (GCRP 2014). Natural stormwater systems in urban areas are frequently built over, which blocks the natural drainage channels. These changes to the natural system combined with the frequency of development within floodplains increases the risk of future climate change driven flooding in urban areas (IPCC 2014b).

Changes in temperature and the time between precipitation events will also affect the wastewater system. Several cities in Washington State are already concerned about the design standards for their drainage systems (IPCC 2014b citing Rosenberg et al. 2010). Britain has identified climate change as a key risk to its sewer system; its models indicate that between increased flooding and increased overflow spills, Britain's volume of sewage could increase by 40 percent (IPCC 2014b citing Tait et al. 2008). New information by Langeveld et al. (2013) indicates that previous studies of impacts of climate change on wastewater systems underestimate the impacts due to model shortcomings and a single focus on precipitation events.

Energy Supply

Climate change will have direct impacts on both the production and the demand side of the energy system by changing hydropower and wind power potential, reducing the efficiency of water cooling for large electricity generating facilities, and changing demands for heating and cooling in developed countries (GCRP 2014; IPCC 2014b citing Mideksa and Kallbekken 2010). It is projected that in most cities in high-income countries, increases in summertime electricity demand due to increased air conditioning use will exceed reductions in winter time electricity use due to decreased heating demands (GCRP 2014 citing Hamlet 2010, IPCC 2014b citing Hammer et al. 2011). In the United States, the electrical grid handles almost the entire cooling load while the heating load is distributed between electricity, natural gas, heating oil, biofuel, and solar. This energy source apportionment amplifies the impact of the increased cooling load on the electrical grid (Dell et al. 2014). These overall increases in energy demand could lead to brownouts and blackouts on hot days as is already regularly experienced in Australia (IPCC 2014b citing Mideksa and Kallbekken 2010, Mirasgedis et al. 2007, and Maller and Strengers 2011). EPA estimates that compared to a control scenario with no temperature change, average U.S. electricity demand is projected to increase by 1.5 to 6.5 percent by 2050 due to increasing temperatures (EPA 2015g).

Many power supply facilities such as power plants, refineries, pipelines, transmission lines, and distribution networks are located in coastal environments and are thus subject to impacts from sea-level rise and storm surges (GCRP 2014). Brown et al. (2014) used a Geographic Information System analysis to determine vulnerable energy sites within the European coastal zone. They concluded that 158 major oil/gas/liquid natural gas/tanker terminals and 71 nuclear reactors are within the coastal zone. The vulnerability of coastal nuclear power plants was demonstrated during Hurricane Sandy when several northeast coastal nuclear reactor plants were shut down due to damages from the storm. The United Kingdom's energy network is particularly vulnerable, with three times as many coastal energy sources as any other European country. In the U.S. Gulf Coast region there are significant offshore marine and coastal facilities that will also be affected by rising sea levels and coastal storms (GCRP 2014 citing Burkett 2011).

Riverine flooding also poses a risk to the energy sector. In 2011 flooding in the Mississippi River basin surrounded a nuclear plant in Nebraska, shut down the substations, and caused wide-ranging energy shortages (Hibbard et al. 2014). Additionally, rail networks frequently follow rivers and are vulnerable to being degraded and washing out during intense precipitation events. In 2011, 42 percent of U.S. electricity was produced by coal that was transported to power plants by rail (GCRP 2014).

Power plants use water for cooling, and in the United States there are restrictions on the maximum discharge water temperature. Periods of drought and rising temperatures are apt to present challenges related to keeping discharge water below these thresholds and to permitting new power plants (GCRP 2014). Warmer discharge water can affect surrounding aquatic ecosystems (GCRP 2014).

Hydropower plants are particularly vulnerable to drought conditions (GCRP 2014). In the western United States, hydropower plants depend on steady streamflows from snowmelt and dams for continuous operation (GCRP 2014). Currently, declining water levels in the Hoover Dam raise concerns for the future of the Los Angeles power grid (IPCC 2014b citing Gober 2010). Drought will also affect the reliability of hydropower in locations such as Brazil and Saharan Africa (IPCC 2014b citing de Lucena et al. 2010, de Lucena et al. 2009, Schaeffer et al. 2011, Muller 2007). Additionally, increased periods of drought can increase wildfire occurrence. Wildfires in California will affect the electricity grid by disrupting transmission and distribution lines (GCRP 2014 citing Sathaye et al. 2013).

An increase in intense storm events could collapse power lines and damage other power transmission infrastructure, leading to electricity outages (IPCC 2014b citing Rosenzweig et al. 2011).

Energy powers a substantial number of systems and critical functions in urban settings. Climate change impacts that decrease the reliability or cause disruptions to the energy supply network could have far-reaching consequences on businesses, infrastructure, healthcare, emergency services, residents, water treatment systems, traffic management, and rail shipping (IPCC 2014b citing Finland Safety Investigations Authority 2011, Halsnæs and Garg 2011, Hammer et al. 2011, and Jollands et al. 2007). An example of the secondary effects of power outages is the 28-hour power outage in New York City in 2003; this outage halted mass transport, debilitated traffic management, and affected the city's water supply (IPCC 2014b citing Rosenzweig and Solecki 2010).

Oil and gas availability in the United States will be affected by increased energy demand in global markets as well as by climate change events. For example, in 2005, Hurricanes Katrina and Rita affected the natural gas, oil, and electricity markets in most of the United States with impacts being felt as far away as New York and New England (GCRP 2014 citing Wilbanks et al. 2012, AWF/AEC/Entergy 2010, Hibbard 2006, and NPCC 2009).

A report by DOE (2013a) highlights climate vulnerabilities of the U.S. energy sector (both traditional energy sources and renewable energy) and the change in energy demand due to climate change. They support the conclusions that thermoelectric power generation is at risk of decreased efficiencies in water cooling systems due to potential heat and water shortages; warming temperatures could decrease energy demand for heating in the winter but could also increase energy demand for cooling during summer months; and significant oil and gas production as well as energy production sources are vulnerable to rising sea levels and storm surges. They also emphasize that water shortages can affect resource (oil and gas) extraction abilities; renewable energy sources (hydropower, bioenergy, and solar) will be affected by changing precipitation and temperatures; electricity transmission efficiencies will decline with increasing temperatures; transmission lines are vulnerable to damage from storms and wildfires; fuel transport via rail and barge is subject to delays due to drought and flooding; and onshore oil and gas production in Alaska will be hampered by damaged infrastructure due to permafrost melt, but offshore operations could benefit from reduced sea ice. Most of these impacts are beginning to be experienced in various regions throughout the United States. The impacts of climate change on the energy sector will vary across regions, but impacts can have cascading consequences that affect other regions.

The effect of climate change on energy in countries where large portions of urban populations do not have consistent access to electricity is relatively unknown (IPCC 2014b citing Johansson et al. 2012, and Satterthwaite and Sverdilk 2012).

<u>Transportation and Telecommunications</u>

Transportation and telecommunications systems are susceptible to damages from extreme events. The daily and seasonal operation of most transportation systems is already sensitive to fluctuations in precipitation, temperature, winds, visibility, and for coastal cities, rising sea levels (GCRP 2014 citing Ball et al. 2010, Cambridge Systematics Inc., and Texas Transportation Institute 2005, and Schrank et al. 2011; IPCC 2014b citing Love et al. 2010). With climate change, the reliability and capacity of the transportation network could be diminished from an increased frequency of flooding and heat events and an increased intensity of tropical storms (GCRP 2014 citing NRC 2008; DOT 2014b). The cost to construct, operate, and maintain the transportation system could also increase (DOT 2014b).

Telecommunication systems are also sensitive to flooding of electrical support systems, wind damages to cellular phone towers, corrosion due to flooding and sea-level rise, and unstable foundations due to permafrost melt (IPCC 2014b citing Zimmerman and Farris 2010, and Larsen et al. 2008). Both transportation and telecommunications are important for disaster response and recovery efforts including evacuation and the provision of food and water following extreme weather events (IPCC 2014b citing Jacob et al. 2011). The impacts of such events are typically experienced more deeply and for longer periods in developing nations where there are no all-weather roads and by low-income residents who are dependent on an operational public transit system (IPCC 2014b).

Transportation assets will be directly affected by a variety of climate changes. Higher temperatures will increase asphalt deterioration and reduce service life by causing pavement and rail line buckling (GCRP 2014 citing Hodges 2011; DOT 2014b). Additionally, expansion joints on bridges and highways will be stressed by higher temperatures (GCRP 2014 citing Meyer 2010) and high air temperatures can affect aircraft performance and lead to delays (GCRP 2014 citing Kulesa 2003). Airports will also be affected by severe weather and precipitation events, affecting arrival and departure rates and potentially limiting aircraft range and payloads (DOT 2014b). Increases in wildfires decrease visibility and can lead to the closure or roads and airports (GCRP 2014). More intense rainfall events and accelerated snowmelt can increase the likelihood of bridge damage from scour due to faster-flowing streams (GCRP 2014 citing Khelifa et al. 2013). Without global GHG mitigation, EPA estimates that 190,000 inland bridges in the United States may be structurally vulnerable to changes in climate by the end of the century. In some areas, over 50 percent of bridges may be vulnerable, requiring increased costs to maintain the current levels of service (EPA 2015g). Increased precipitation can result in the flooding of underground tunnels, requiring additional drainage and pumping to maintain service (DOT 2014b). Transportation drainage systems and culverts could be damaged by changes in precipitation intensity and snow melt timing (DOT 2014b). Rail networks are known to fail due to high temperatures, icing, and storms (IPCC 2014b). On the other hand, decreased snow can lead to reduced snow removal costs and longer construction seasons (GCRP 2014). Based on cost and assuming no mitigation of GHG, the greatest regional impacts to U.S. road infrastructure are projected to occur in the Great Plains due to the erosion of unpaved roads from increased precipitation (EPA 2015g). On the other hand, the costs of resealing roads after freeze-thaw events is projected to decrease as temperatures rise (EPA 2015g).

Transportation assets in coastal locations are particularly vulnerable to climate change impacts. In the Gulf Coast region of the United States, 27 percent of major roads, 9 percent of rail lines, and 72 percent of ports are within 4 feet of current sea levels. When potential storm surge impacts are considered, even more transportation assets are vulnerable to sea-level rise and land subsidence (IPCC 2014b citing Savonis et al. 2008). A case study in Hampton Roads, Virginia, found similarly high coastal vulnerabilities and less severe but still present inland risks (Wu et al. 2013). Additionally, 13 of the nation's largest 47 airports are within 12 feet of current sea levels (GCRP 2014 citing FAA 2012). Examples of damage to coastal infrastructure resulting from sea-level rise, storm surge, and waves include:

- Damage to coastal bridges due to waves and storm surge (Douglass et al. 2014).
- Damage to roadways and railways due to waves and storm surge (Douglass et al. 2014).
- Damage to roadways on coastal bluffs from bluff erosion and shoreline recession due to waves and wave run-up (Douglass et al. 2014).
- Damage resulting from flooding or overtopping of highways and tunnels (Douglass et al. 2014, DOT 2014b).
- Shortened infrastructure life from increased frequency and magnitude of storm surge and sea-level rise (DOT 2014b).

Hurricanes create high winds and storm surges that cause flooding, both of which can disrupt all transportation systems within the affected area (GCRP 2014). In 2012, Hurricane Sandy demonstrated this by shutting down New York City's bridges, tunnels, and airports. In addition, an estimated 230,000 vehicles were damaged (GCRP 2014 citing National Insurance Crime Bureau 2013), and all electrical signaling and power systems in the tunnels had to be cleaned and repaired (GCRP 2014).

Ports and harbors could have to be reconfigured to accommodate higher sea levels and large vessel clearance under bridges will need to be considered (DOT 2014b, GCRP 2014). Even if the elevation of the port is sufficient, the roads and rail lines that access the port could be subject to more frequent inundation, thus affecting port activities (GCRP 2014). Additionally, shipping channels could become blocked due to increased sediment transport with extreme floods and storms (GCRP 2014). Droughts can cause similar problems by leading to lower vessel drafts on navigable rivers (GCRP 2014). For the week following Hurricane Sandy in New York, one of the busiest container shipping ports in the United States was debilitated due to damage from the storm (IPCC 2014b citing Hallegatte et al. 2013). The impacts of this storm were felt across the country due to this port closure and other disruptions to the economy.

Transportation systems can also be affected indirectly by climate change leading to changing mode choices, trade flows, energy use, and land use patterns (GCRP 2014, DOT 2014b). For example, if crop cultivation shifts farther north with rising temperatures, then distribution networks for those crops would need to be altered, which could affect the use of various network links (GCRP 2014 citing Vedenov 2011; DOT 2014b). Changes in temperatures and precipitation have been shown to affect transit ridership, bicycling, and walking (GCRP 2014 citing Hodges 2011, Aultman-Hall et al. 2009, and Guo et al. 2007).

The National Cooperative Highway Research Program (NCHRP) recently released a report on the potential impacts of climate change on highways in the United States (2014).

Highlights of its findings include:

- Increased temperatures can increase asset deterioration and pavement rutting.
- Extreme heat can lead to steel bridge joint expansion.
- Warmer winters could reduce the need to clear snow from roadways, but they could also increase the frequency of freeze–thaw cycles that would result in potholes and pavement heaving.
- Melting permafrost in Alaska will likely damage asset foundations and lead to decreased wintertime ice road networks.
- Increased precipitation events can lead to roadway flooding and could lead to landslides and slope failures due to increased soil moisture content.
- Bridges are vulnerable to increased wind loads as well as scour from high rates of river runoff.
- Sea-level rise (especially combined with local land subsidence and storm surge events) can lead to roadway flooding and temporary or permanent inundation.
- Underground tunnels and deep foundations could be affected by the encroachment of saltwater, which degrades many building materials.

All climate stressors will also impact the maintenance and operations of transportation assets (NCHRP 2014). For example, construction workers could have to work an altered schedule to avoid heat stroke (GCRP 2014 citing NIOSH 1986).

Hambly et al. (2013) discuss the implications of climate change on driver safety. With projected increases in high intensity precipitation events, it is expected that collision rates will increase by the mid-2050s in the Greater Vancouver Metropolitan Area. The U.S. Department of Transportation (2014b) also acknowledges the increased risk of collision in severe weather and the increased risk of poor driver/operator performance and decisionmaking skills due to fatigue related to adverse weather.

Lastly, the indirect cost of climate change impacts on transportation systems, including delays and trip cancellations, could be substantial to the economy (IPCC 2014b, GCRP 2014).

Built Environment, Recreation, and Heritage Sites

Housing in urban areas is one of the pieces of infrastructure most heavily impacted by extreme weather events such as cyclones and floods (IPCC 2014b citing Jacobs and Williams 2011). Housing that is constructed out of informal building materials (usually occupied by low-income residents) and without strict building codes is particularly vulnerable to extreme events (IPCC 2014b citing United Nations 2011). Increased weather variability including warmer temperatures, changing precipitation patterns, and increased humidity accelerates the deterioration of common housing building materials (IPCC 2014b citing Bonazza et al. 2009, Grossi et al. 2007, Smith et al. 2008, Stewart et al. 2011, and Thornbush and Viles 2007). Loss of housing due to extreme events and shifts in climate patterns is linked to displacement, loss of home-based businesses, and health and security issues (IPCC 2014b citing Haines et al. 2013). In 2012, the storm surge from Hurricane Sandy severely impacted coastal communities, many of them low- to moderate-income. Tens of thousands were displaced by this event, and others (especially the elderly) were left stranded on upper floors of apartment buildings without elevator service (GCRP 2014). Without global GHG mitigation, EPA estimates that sea-level rise and storm surge will result in cumulative damages to coastal property across the contiguous United States of US$5 trillion through 2100 if no adaptive measures are taken (EPA 2015g).

There is less research on the effects of climate change on urban recreation, tourism, and historical structures (IPCC 2014b). Parks and playgrounds in low-lying areas (and potentially others) such as in New York City are subject to sea-level rise and storm surge (IPCC 2014b citing Rosenzweig and Solecki 2010). Risks similar to those that apply to housing also apply to historical structures. The United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Human Settlements Programme (UN-HABITAT), European Commission, and individual city mayors have come together to assess how to protect historical structures from climate change (IPCC 2014b). Even without additional warming, the oceans will continue to expand over the next 2 millennia in response to warming that has already occurred. Marzeion and Levermann (2014) estimate that the resulting sea-level rise will lead to the inundation of 40 UNESCO Cultural World Heritage Sites. If temperatures increase by 3°C (5.4°F), 136 sites will be vulnerable to sea-level rise flooding by the time the thermal expansion of the oceans is complete (approximately 2 millennia).

Green Infrastructure and Ecosystem Services

Ecosystems will be affected by climate change induced “changes in temperature and precipitation regimes, evaporation, humidity, soil moisture levels, vegetation growth rates (and allergen levels), water tables and aquifer levels, and air quality” (IPCC 2014b). “Green infrastructure” involves using ecosystems to naturally maintain, manage, and remediate existing and new natural and urban areas. Investments in green infrastructure are projected to be affected by increasing precipitation variability, climate change, and urban heat island induced heat stress, new pest attacks, and sea-level rise inundation (IPCC 2014b citing Gaffin et al. 2012, Tubby and Webber 2010, and Kithiia and Lyth 2011).

Health and Social Services

Climate change will also impact urban public services such as healthcare and social care services, education, police, and emergency services (IPCC 2014b citing Barata et al. 2011). In developed countries, existing emergency response and public health plans can be used to respond to some extreme climate events, but other events will require additional considerations (IPCC 2014b citing Bedsworth 2009 and McMichael et al. 2008). For more information on climate change and health impacts, *see* Section 5.5.2.7. In low- and middle-income countries, many of these public services are currently lacking and will only be made less available with climate change impacts (IPCC 2014b citing Brody et al. 2010).

Water shortages can lead to reliance on poorer quality water sources and can increase the likelihood of contracting waterborne illnesses. Changes in temperature extremes will also impact health through heat stress (IPCC 2014b) and changes in air quality (IPCC 2014b citing Athanassiadou et al. 2010); however, impacts of climate change on air quality in particular locations is highly uncertain (IPCC 2014b citing Jacob and Winner 2009, and Weaver et al. 2009). Worsening air quality can inflame asthma and allergen problems (IPCC 2014b citing Barata et al. 2011, Gamble et al. 2009, Kinney 2008, O'Neill and Ebi 2009, and Reid et al. 2009). *See* Section 5.5.2.7 for additional information.

5.5.2.5.3 Adaptation

Adapting urban centers will require substantial coordination between the private sector, multiple levels of government, and civil society, but early action by urban governments is key to successful adaptation since adaptation measures need to be integrated into local investments, policies, and regulatory frameworks (IPCC 2014b). Additionally, local assessments of risks and vulnerabilities are necessary for informing appropriate adaptation strategies. While these analyses are becoming more common they are by no means comprehensive (IPCC 2014b).

Existing risk reduction plans, such as public health and natural hazard mitigation plans, provide strong foundations for the development of more comprehensive and forward thinking documents that address increasing exposure and vulnerability (IPCC 2014b). Additionally, urban areas that already have a strong government structure and universal provision of infrastructure and services are best prepared for adapting to climate change.

The provision of good quality, affordable housing would go a long way towards minimizing exposure and loss. This adaptation effort relies upon the private sector for successful implementation (IPCC 2014b). Additionally, maintaining existing infrastructure and building new infrastructure to be resilient to climate change (including water supply, sanitation, stormwater, wastewater, electricity, transport, telecommunications, healthcare, education, and emergency response infrastructure) can significantly reduce exposure and vulnerability (IPCC 2014b). Along with this built infrastructure, ecosystem services need to be considered in adaptation options (IPCC 2014b).

Financing adaptation strategies could be one of the largest hurdles to overcome; however, urban adaptation can enhance the economic competitiveness of an area by reducing risks to businesses, households, and communities (IPCC 2014b). Additionally, there are emerging synergistic options for urban adaptation measures that also deliver GHG emissions reductions co-benefits (IPCC 2014b).

5.5.2.6 Rural Areas

This section defines rural areas and describes the existing conditions and potential vulnerability to climate change impacts.

There is no clear definition of rural areas—frequently, rural areas are simply defined as areas that are not urban (IPCC 2014b citing Lerner and Eakin 2010). A consistent definition is difficult to reach because human settlements exist along a continuum from urban to rural with many varied land use forms in-between and varying development patterns between developed and developing countries. It is frequently noted that relying on the broad classifications of "urban" and "rural" is problematic for researchers (IPCC 2014b citing Simon et al. 2006). In general, the IPCC and this EIS accepts the definitions of urban and rural used by individual countries and individual academic authors in their work.

Rural areas are subject to unique vulnerabilities to climate change due to their dependence on natural resources, their reliance on weather-dependent activities, their relative lack of access to information, and the limited amount of investment in local services (IPCC 2014b). These rural vulnerabilities have the potential to significantly impact urban areas due to the complex connections between the communities. For example, rural areas in the United States provide much of the rest of the country's food, energy, water, forests, and recreation (GCRP 2014 citing ERS 2012).

Rural areas account for almost half of the world's total population and an even greater percentage of people in developing countries (IPCC 2014b citing UN-DESA Population Division 2013). The U.S. Census Bureau classifies more than 95 percent of the land area in the United States as rural but only 19 percent of the population calls these areas home (GCRP 2014 citing HRSA 2012, U.S. Census Bureau 2012a, 2012b, and USDA 2012). In the United States, modern rural populations are generally more vulnerable to climate change due to various socioeconomic factors (e.g., age, income, education) (GCRP 2014).

5.5.2.6.1 Summary

Climate change will impact rural populations' water supplies (due to glacial retreat, drought, extreme precipitation events, and increasing demands on water for irrigation), food security, agricultural incomes (through shifts from growing crops to raising livestock and changing regions appropriate for the production of non-food/high-value crops), infrastructure (including energy, transportation, and telecommunications), fisheries (due to rising ocean temperatures), and the economic benefits of rural recreation and tourism (due to declining snow packs and rising sea levels).

Rural populations in low- and medium-income countries will experience the most extreme climate change impacts due to their existing vulnerabilities to climate variability and the lack of reserves/redundancy in their critical infrastructure and services. However, increases in international trade could temporarily alleviate some of the impacts of climate change, such as food scarcity (IPCC 2014b).

Gradual changes in the climate are unlikely to affect human migration due to larger stresses such as social and political change. However, there will be substantial migration following extreme events and loss of land due to sea-level rise (IPCC 2014b).

5.5.2.6.2 Observed and Projected Climate Impacts

Climate change affects rural areas through a complex string of impacts. These impacts generally follow one of two formats: (1) extreme events that immediately impact infrastructure, and (2) long-term changes to natural systems and agriculture.

Detecting and attributing extreme events and the impacts of climate change in rural areas presents significant challenges (IPCC 2014b citing Seneviratne et al. 2012), as there are complications with relying upon traditional knowledge and farmers' perceptions to detect long-term climate trends (IPCC 2014b citing Rao et al. 2011). However, at least in Malawi, there has appeared to be a convergence between climate data and local perceptions of change over the last 30 years (IPCC 2014b citing Wellard et al. 2012).

Events that have a negative impact on rural areas include tropical storms which can lead to sudden flooding and wind damage, droughts and temperature extremes which can increase water scarcity and thus kill livestock and effect agricultural yields (IPCC 2014b citing Handmer et al. 2012 and Ericksen et al. 2012), inland flooding, and wildfires (Hales et al. 2014). In the United States, rural areas have already experienced crop and livestock loss from extreme drought and flooding (GCRP 2014 citing Peterson et al. 2012), infrastructure damage to levees and roads from extreme storms (GCRP 2014 citing DOT 2010), shifts in agricultural planting and harvesting seasons (GCRP 2014 citing Kunkel et al. 2009), and large-scale losses from wildfires and other weather-related disasters (GCRP 2014 citing Westerling et al. 2006). In Alaska, shrinking sea ice and changing seasonal ice are affecting indigenous peoples (IPCC 2014b citing Ford 2009, Beaumier and Ford 2010; IPCC 2014b). Glacial retreat in Latin America is clearly impacting rural life in highland Peru where there have been observed rapid declines in dry-season streamflow since 1962 (IPCC 2014b citing Orlove 2009).

In Asia and the Pacific, it is estimated that 42 million people have been displaced by extreme weather events between 2010 and 2011 (IPCC 2014b citing Asian Development Bank 2012). While this migration of peoples cannot be solely attributed to climate change, it could have been modified or exacerbated by climate change induced events.

The reminder of this section will focus on the impacts on rural agricultural livelihoods, non-food crops, livestock and fisheries, and water as an input to agriculture. In general, it is agreed that some African countries will experience higher losses than other regions. This holds true across a suite of climate models and emissions scenarios (IPCC 2014b citing World Bank 2010a, Watkiss et al. 2010, and Collier et al. 2008).

Economic Base and Livelihoods

Climate change will affect the ability of rural communities to maintain their ways of life. Rural livelihoods are less diverse than their urban counterpoints and are frequently dependent on natural resources that have unknown future availability such as agriculture, fishing, and forestry (IPCC 2014b, GCRP 2014). Due to this lack of economic diversity, climate change will place disproportionate stresses on the stability of these communities (GCRP 2014). The impacts of climate change will be amplified by the impacts on surrounding sectors within rural communities' spheres of life, such as impacts on economic policy, globalization, environmental degradation, human health, trade, and food prices (IPCC 2014b citing Morton 2007 and Anderson et al. 2010). In addition, the post-harvest aspects of agriculture such as storage and transport of crops will be affected by changes in temperature, rainfall, humidity, and extreme events (IPCC 2014b). However, in the short term, the U.S. agricultural system will likely be able to maintain its crop production by expanding irrigated land, by practicing crop rotations or shifting to different crops, and through changes in management decisions (GCRP 2014).

The increasing percentage of non-agricultural livelihoods in rural and peri-urban areas will also be affected by climate change but there is a scarcity of literature on this subject (IPCC 2014b).

Local warming "in excess of 1°C [1.8°F] is projected to have negative impacts in both temperate and tropical regions without adaptation (though individual locations may benefit). There is *medium confidence* in large negative impacts of local increases of 3 to 4°C [5.4 to 7.2°F] on productivity, production, and food security, globally and particularly in tropical countries" (IPCC 2014b).

Water

In lakes and riparian areas, it is projected that there will be an increase in algal blooms and invasive species due to rising temperatures. This will particularly be an issue in locations that already face limited sources of clean water (GCRP 2014 citing Hansson et al. 2012). Additionally, with increased intensity and frequency of precipitation events, there will be an acceleration of soil erosion rates; this erosion will diminish water quality by depositing nitrogen and phosphorous into waterbodies and by increasing algae blooms (GCRP 2014 citing Delgado et al. 2011).

Rural areas frequently depend on groundwater extraction and irrigation for local agriculture, but the availability of water from these sources is infrequently considered in projections of future crop yields (IPCC 2014b citing Lobell and Field 2011). Reduced surface water will increase the stress on groundwater and irrigation systems (GCRP 2014).

Around the world, competition for water resources will increase with population growth and other uses such as energy production (IPCC 2014b, GCRP 2014). High temperatures increase energy demand for air conditioning which leads to increased water withdrawal for energy production. At the same time, the heat also dries out the soil which increases irrigation demands, and the warmer water threatens to shut down energy production (GCRP 2014). In the United States, water withdrawals for generating electricity in thermal power plants already roughly equals irrigation withdrawals, and this tension is expected to continue (GCRP 2014 citing Hutson et al. 2004). Multiple water crises are expected to result from increasing demand. In particular, Asian river basins could experience water scarcity and food security issues (IPCC 2014b citing Immerzeel et al. 2010). In parts of Asia and the western United States, Haddeland et al. (2014) found that anthropogenic water use (mostly for irrigation) will lead to significant future water shortages; these water shortages will be twice as severe if coupled with a 2 to 3°C (3.6 to 5.4°F) increase in global mean temperatures. Demand for irrigation water will increase with an increase in global mean temperatures which will lead to irrigation water scarcity in areas such as southern and eastern Asia (Haddeland et al. 2014). In Africa, it is predicted that there will not be widespread catastrophic failure of the rural groundwater supplies, but there could be stress on groundwater aquifer refill in rural areas where annual rainfall is only between 200 and 500 millimeters (7.9 and 19.7 inches), annually affecting up to 90 million people (IPCC 2014b citing Macdonald et al. 2009). In southern Europe, changes in rainfall and meltwater from glacial ice and snow could impact the cost of production of agriculture, and thus, raise the cost of living (IPCC 2014b citing Falloon and Betts 2010).

Non-Food Crops and High-Value Food Crops

Non-food crops and high-value food crops such as cotton, wine grapes, beverage crops (coffee, tea, and cocoa), and other cash crops contribute to an important source of income to rural locations. However, these crops tend to receive less study than staple food crops (IPCC 2014b). Cotton yields are projected to rapidly decrease with changes in temperature and precipitation (IPCC 2014b citing Easterling et al. 2007). In Israel, between 2070 and 2100, cotton cultivation could decline from the base 1960 through 1990 levels by 52 percent to 38 percent under the higher (A2) and lower (B2) emissions scenarios, respectively (IPCC 2014b citing Haim et al. 2008).

Wine grapes will be impacted but not as rapidly as other crops. It is anticipated that in California the yield variation will be limited to within 10 percent (IPCC 2014b citing Gatto et al. 2009). However, wineries could have to shift the varietals that they grow, and new regions could become better suited to growing wine grapes. Across all Mediterranean climate regions, Hannah et al. (2013) found that under the higher emissions scenario (RCP 8.5), by 2050 the historical areas suitable for viticulture could decrease by 25 to 73 percent. Under the lower emissions scenario (RCP 4.5), changes in suitable areas for viticulture are anticipated to be reduced by 19 to 62 percent. However, it is possible that viticulture could shift to non-traditional regions that, with climate change, become more suitable for growing grapes.

Coffee is historically sensitive to changes in temperature and precipitation. Coffee production in Mexico is likely to decline by 34 percent by 2020 if climatic trends from 1969 through 1990 of decreased spring precipitation and increased summer and winter temperatures continue. This would reduce profits by 90 percent (IPCC 2014b citing Gay et al. 2006). Brazil, the world's largest coffee grower, will see substantial decreases in the suitability of coffee production in some states while other states will only be partially affected. While some new areas will become suitable for coffee production, these new areas will not make up for the loss of suitable areas experienced with a 3°C (5.4°F)-increase in temperatures (IPCC 2014b citing Pinto et al. 2007, Pinto and Assad 2008). Similar changes of 30 to 60 percent loss in land suitable for coffee growing is projected in parts of Africa and South and Central America over the next few decades (IPCC 2014b). Overall, there is a worldwide projected reduction in areas suitable for coffee production by 2050 (IPCC 2014b citing Laderach et al. 2010).

Livestock/Fisheries

Livestock will be affected by droughts and heat stress, declines in forage/rangeland areas, and changes in diseases (IPCC 2014b). In general, livestock and climate change have been understudied but they remain critical to rural populations. More land could be converted to livestock (sheep and goat) production once it can no longer bear crops (IPCC 2014b citing Seo and Mendelsohn 2007a). Large-scale beef production could decline because these are generally non-diversified productions with already high stress on their systems (IPCC 2014b citing Seo and Mendelsohn 2007b).

Pastoralists lead nomadic lives in pursuit of high-quality grazing land. Their traditional way of life is well accustomed to adapting to a changing climate, but pressures to decrease their mobility is increasing in sub-Saharan Africa and inner Mongolia, making these communities subject to climate change impacts in arid and semi-arid regions (Krätli et al. 2013; IPCC 2014b citing Lioubimtseva and Henebry 2009 and Fraser et al. 2011).

Fisheries could be affected by changes in fish stock distribution and abundance due to changes in their habitats and destruction of fishing infrastructure in storm events (IPCC 2014b citing Badjeck et al. 2010). Over the last 40 years, with increasing ocean temperatures, fisheries in the subtropics and temperate regions of the globe have been experiencing a shift in catch from colder-water species to warmer-water species as fish migrate to higher latitudes and deeper waters to remain within their preferred mean water temperature zone (Cheung et al. 2013). In the tropics, overall fish populations are declining as tropical fish migrate to colder waters at higher latitudes (Cheung et al. 2013). This trend is expected to continue with some mountain and cold water species declining in range and warmer species, such as bass, expanding in range (GCRP 2014 citing Janetos et al. 2008). The decline in cold water fish, such as salmon, will significantly impact traditional Inuit populations who depend on salmon as a food source (GCRP 2014). In the Mediterranean Sea, Tzanatos et al. (2014) found that there is a strong year-to-year correlation between warmer than average annual water temperatures in the late 1990s and decreases in the catch of 25 out of 59 commercial fish species. However, in those same years there has been an increase in the catch of species with short life spans (approximately 11 of the 59 fish demonstrated this correlation).

A less researched area is the effect of climate change on mining operations (GCRP 2014). These operations frequently support rural communities with few other economic options; if a mine's economic viability falters then so does that of the community. Mining and extraction will be affected by changes in the water, energy, and transportation sectors (IPCC 2014b, GCRP 2014).

Infrastructure

Impacts of climate change on rural infrastructure is similar to that in urban areas (*see* Section 5.5.2.5) but frequently there is less redundancy in the system so assets are more vulnerable to hydroclimatological events (GCRP 2014, IPCC 2014b citing NRC 2008). River flooding, sea-level rise, and coastal storms will damage transportation infrastructure and lead to the temporary loss of land activities either directly or through increased sediment transport; this can overwhelm roads or clog reservoirs (IPCC 2014b citing Kirshen et al. 2008; GCRP 2014 citing Gill et al. 2009). Alternatively, decreased precipitation can decrease sediment transport and allow for easier operation of some infrastructure (IPCC 2014b citing Wang et al. 2007).

Warmer temperatures will lead to thawing of the permafrost in the arctic which will destabilize roads, rails, runways, pipelines, telecommunications, and bridges that are constructed on permafrost (Schwartz et al. 2014 citing Arctic Council 2009; IPCC 2014b citing Prowse et al. 2009). In Alaska, under the moderate (A1B) emissions scenario, this could lead to a 10 to 20 percent increase in public infrastructure costs from 2007 through 2030 and a 10 to 12 percent increase from 2007 through 2080. These cost increases sum to billions of dollars over both of the analysis time periods (IPCC 2014b citing Larsen et al. 2008). Additionally, warmer temperatures in the winter months could result in a loss of sea ice which could increase shipping opportunities but also reduce coastal protection leading to erosion of the shoreline and coastal roads. Canada could have to replace its winter road network which serves rural areas and lucrative mining activities if there is a 2 to 4°C (3.6 to 7.2°F) change in ground surface temperatures (IPCC 2014b citing Furgal and Prowse 2008).

Spatial and Regional Interconnections

Rural communities are becoming more connected to urban ones, but human migration from rural to urban areas is likely no higher under climate change than under regular conditions. This diverges from previous assumptions of increased migration (IPCC 2014b). There will be increased migration following extreme events that lead to the destruction of local communities, but there will be little migration due solely to slow environmental degradation. More migration will be linked to additional stressors such as political instability and socioeconomic factors (IPCC 2014b citing van der Geest 2011). However, Native American communities are already being forced to relocate due to rising sea levels and coastal erosion (GCRP 2014). In the future, rural communities on low-lying islands and atolls will have to relocate due to sea-level rise (Birk and Rasmussen 2014).

International trade (both volume and value) is expected to increase *(medium agreement and limited evidence*) by "altering the comparative advantage of countries and regions and given its potential impact of agricultural prices" (IPCC 2014b citing Nelson et al. 2009, 2010, 2013b, and Tamiotti et al. 2009). In general, exports from developed to developing countries are expected to increase, this would lower the global cost of food and thus help alleviate food insecurity, but caution should be exercised to ensure that the increased crop land is not leading to detrimental environmental consequences from loss of forests (IPCC 2014b citing Verburg et al. 2009, Schmitz et al. 2012, and Lotze-Campen et al. 2010). Increased production of biofuels will decrease emissions but could have negative benefits on society as well. Biofuel production will affect rural societies by increasing water demand, affecting water quality, and altering land uses (IPCC 2014b citing Delucchi 2010). Additionally, in 2012, drought led to poor corn harvests in the United States, intensifying concerns about mandated ethanol use and the tension between harvests being allocated to biofuels versus food (Hibbard et al. 2014). Investment in rural communities could vary with climate change. Areas that will be negatively affected will likely not attract many investors, while regions that will become more suited for development and production will receive increased investment (IPCC 2014b).

Recreation and Tourism

There is a strong link between biodiversity, tourism, rural livelihoods, and rural landscapes in both developed and developing countries (IPCC 2014b citing Nyaupane and Poulde 2011, Scott et al. 2007, Hein et al. 2009, Wolfsegger et al. 2008, and Collins 2008). Tourism patterns could be affected by changes to the length and timing of seasons, temperature, precipitation, and severe weather events (GCRP 2014). Changes in the economic values of traditional recreation and tourism locations will affect rural communities because tourism makes up a significant portion of rural land use (IPCC 2014b citing Lal et al. 2011). Coastal tourism, nature-based tourism, and winter sports tourism could be affected by climate change. Coastal tourism is vulnerable to cyclones and sea-level rise (IPCC 2014b citing Klint et al. 2012 and Payet and Agricole 2006) as well as beach erosion and saline intrusion (IPCC 2014b). The Florida Everglades and Florida Keys are particularly threatened by sea-level rise (GCRP 2014 citing Stanton and Ackerman 2007). Some areas, such as Maine, may see increases in coastal tourism due to warmer summer months (GCRP 2014 citing Burkett and Davidson 2012). Nature-based tourism will be affected by declining biodiversity and harsher conditions for trekking and exploring (IPCC 2014b citing Thuiller et al. 2006 and Nyaupane and Chhetri 2009). Winter sport tourism will be affected by declining snow packs and precipitation falling more frequently as rain rather than snow due to warmer temperatures (IPCC 2014b). In the western United States, snow accumulation has already decreased and is projected to continue to decrease due to increasing temperatures (GCRP 2014). Similar changes are expected in the northeastern United States (GCRP 2014 citing Pietrowsky et al. 2012). Tourism itself has led to increased vulnerability to climate change by encouraging coastal development in the Caribbean (IPCC 2014b citing Potter 2000).

5.5.2.6.3 Adaptation

Rural adaptation will build upon community responses to past climate variability; however, this could not be enough to allow communities to fully cope with climate impacts (IPCC 2014b). Temporary responses to food and water shortages or extreme events could even increase the long-term vulnerability of a community. For example, in Malawi, forest resources are used for coping with food shortages, but this deforestation enhances the community’s vulnerability to flooding (IPCC 2014b citing Fisher et al. 2010). Therefore, it could be necessary to look beyond local examples of adapting and borrow adaptation strategies from other regions that are already experiencing more severe climate trends. This will allow for the development of long-term strategies that not only respond to climate events but minimize future vulnerabilities (IPCC 2014b citing Vincent et al. 2013). Funding for adaptation in rural areas could be linked to other development initiatives that aim to reduce poverty or generally improve rural areas (IPCC 2014b citing Nielsen et al. 2012, Hassan 2010, and Eriksen and O’Brien 2007).

5.5.2.7 Human Health

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. This section describes the climate impacts related to extreme events, heat and cold events, air quality, aeroallergens, water- and food-borne diseases, vector-borne diseases, cancer, and indirect impacts on health.

5.5.2.7.1 Summary

The state of the science shows that climate change can affect human health in a variety of ways. These effects range from direct impacts from extreme temperatures and extreme weather events, to changes in prevalence of diseases, and indirect impacts from changes to agricultural productivity, nutrition, conflict, and mental health. Across all potential impacts, disadvantaged groups such as children, elderly, sick, and low-income populations are especially vulnerable.

5.5.2.7.2 Observations and Projections of Climate Impacts

Extreme Events

Health impacts associated with climate-related changes in exposure to extreme events (e.g., floods, droughts, heat waves, severe storms) include death, injury, illness, or exacerbation of underlying medical conditions. Climate change will increase exposure risk in some regions of the United States due to projected increases in frequency and intensity of drought, wildfires, and flooding related to extreme precipitation, rising temperatures, and hurricanes (EPA 2016e). Specifically, climate change will increase exposure risk to coastal flooding due to increases in extreme precipitation, hurricane intensity and rainfall rates, and sea-level rise and the resulting increases in storm surge (EPA 2016e). Many types of extreme events related to climate change cause disruption to infrastructure—including power, water, transportation, and communication systems—that are essential to maintaining access to health care and emergency response services that safeguard human health (EPA 2016e).

Extreme weather conditions can increase stress population-wide, which can exacerbate mental health problems for those who already have them and even create them in those without (EPA 2016e, IPCC 2014b). For example, research has shown high levels of anxiety and post-traumatic stress disorder among people affected by natural disasters such as Hurricane Katrina (GCRP 2014 citing Galea et al. 2007, Kessler et al. 2008, Ahern et al. 2005, Fewtrell and Kay 2008, Hansen et al. 2008, and McFarlane and Van Hooff 2009). Children, the elderly, women, people with preexisting mental illness, the economically disadvantaged, the homeless, and first responders are at higher risk for distress and adverse mental health consequences from exposure to climate-related disasters (EPA 2016e).

Heat and Cold Events

One direct way that climate change is projected to affect human health is through changes in temperature extremes. This effect has been seen in the past and is projected to continue and worsen in the future. For example, the 2003 heat wave in Europe was responsible for about 15,000 excess deaths in France alone (IPCC 2014b citing Fouillet et al. 2008), and there is a 75 percent chance that the heat wave can be attributed to climate change (IPCC 2014b citing Christidis et al. 2012). The United Kingdom could experience a 257 percent increase in heat-related deaths by the 2050s compared to an annual baseline of 2,000 deaths under the moderate (A1B) emissions scenario and assuming no adaptation (conversely, cold-related deaths could decline by 2 percent from the current baseline of 41,000 deaths) (Hajat et al. 2014). Even small differences from seasonal average temperatures result in death and illness (EPA 2016e). Across 105 U.S. cities, an increase in average annual temperature of 5°F could lead to an increase in mortality by 1,907 deaths per summer, even with additional adaptation measures instigated to cope with heat (Bobb et al. 2014). However, one new study notes that projections of heat-related mortality could be overly simplified in that they often are based on only one temperature variable and do not account for variable urban heat island effects across locations and times of day (Hondula et al. 2014). An increase in population tolerance to extreme heat has been observed over time, and changes in this tolerance have been associated with increased use of air conditioning, improved social responses, and physiological acclimatization (EPA 2016e).

The largest health impacts from heat events are likely to occur in tropical developing countries, where large and already vulnerable populations would be exposed (IPCC 2014b citing Wilkinson et al. 2007). Further, in all parts of the world, the youngest, oldest, and poorest members of society are most vulnerable to health impacts from heat and cold events (EPA 2016e, GCRP 2014). For example, those with lower incomes could have less access to air conditioning/heating (IPCC 2014b citing Ostro et al. 2010) or could have jobs with physically strenuous working conditions (IPCC 2014b citing Kjellstrom et al. 2011, Kjellstrom et al. 2009, and Sahu et al. 2013).

Warming associated with climate change could contribute to a decline in cold-related deaths, but evidence suggests that the impacts from extreme heat events greatly outweigh any benefits from decreases in cold-related deaths (EPA, 2016e; EPA 2015g; IPCC 2014b citing Ebi and Mills 2013, Kinney et al. 2012; Medina-Ramón and Schwartz 2007; GCRP 2014 citing Yu et al. 2011, Li et al. 2013; Hajat et al. 2014).

Air Quality

Climate change may also negatively affect human health by increasing ground-level ozone or particulate matter in some locations, degrading air quality. Without global GHG mitigation, Eastern, Midwestern, and Southern states are most likely to experience degraded air quality associated with climate change (EPA 2015g). Ozone production could increase with rising temperatures, especially in urban areas (IPCC 2014b citing Chang et al. 2010, Ebi and McGregor 2008, Polvani et al. 2011, and Tsai et al. 2008). Unless offset by additional emissions reductions of ozone precursors, these climate-driven increases in ozone will cause premature deaths, hospital visits, lost school days, and acute respiratory symptoms (EPA 2016e). Even small increases in ground-level ozone concentrations can affect health (IPCC 2014b, GCRP 2014 citing Dennekamp and Carey 2010, Kampa and Castanas 2008, Kinney 2008, and Anderson et al. 2012). For example, one study projects that emergency room asthma visits associated with ozone exposure could increase by 5 to 10 percent in the New York metropolitan region under the higher (A2) emissions scenario by the mid-2020s relative to the mid-1990s (GCRP 2014 citing Sheffield et al. 2011a).

Climate change can also affect air quality through an increasing number of wildfires and changing precipitation patterns. Wildfires produce particulate matter pollutants and ozone precursors that diminish both air quality and human health (EPA 2016e, GCRP 2014). Thus, climate change could degrade air quality through a variety of mechanisms, including increased temperatures and wildfires as mentioned, but also changes in vegetative growth, increased summertime stagnation events, and increased absolute humidity (GCRP 2014 citing Peel et al. 2013). Further, climate change is projected to increase flooding in some locations both in the United States (GCRP 2014 citing IPCC 2007b and IPCC 2012) and around the world (IPCC 2014b citing IPCC 2012). Combined with higher air temperatures, this could foster the growth of fungi and molds, diminishing indoor air quality, particularly in poor communities (GCRP 2014 citing Fisk et al. 2007, Institute of Medicine 2011, Mudarri and Fisk 2007, and Wolf et al. 2010).

Aeroallergens

Increased temperatures and CO_2 concentrations can shift or extend plant growing seasons, including those of plants that produce allergens and pollen (EPA 2016e, GCRP 2014 citing Sheffield et al. 2011a, Emberlin et al. 2002, Pinkerton et al. 2012, Schmier and Ebi 2009, Shea et al. 2008, Sheffield and Landrigan 2011, and Ziska et al. 2011). These effects are already occurring worldwide and are projected to continue with climate change (D'Amato et al. 2013, GCRP 2014, IPCC 2014b). For example, in central North America, length of the season for ragweed pollen has increased between 11 and 27 days in response to rising temperatures between 1995 and 2011 (GCRP 2014 citing Ziska et al. 2011).

Increases in pollen and other aeroallergens can exacerbate asthma and other health problems such as conjunctivitis and dermatitis (EPA 2016e, IPCC 2014b citing Beggs 2010). It has also been known to reduce school and work productivity (GCRP 2014 citing Ziska et al. 2011, Sheffield et al. 2011b, and Staudt et al. 2010).

Water- and Food-borne Diseases

Climate—in terms of both temperature and precipitation—can influence the growth, survival, and persistence of water- and food-borne pathogens (EPA 2016e, IPCC 2014b). For example, heavy rainfall and increased runoff promote the transmission of water-borne pathogens and diseases in recreational waters, shellfish harvesting waters, and sources of drinking water (EPA 2016e). Diarrheal disease rates are also linked to temperatures (IPCC 2014b). For example, one study projects that temperature increases due to climate change could cause an 8 to 11 percent increase in the risk of diarrhea in the tropics and subtropics by 2010 to 2039 relative to the baseline period 1961 to 1990, using the moderate (A1B) emissions scenario (IPCC 2014b citing Kolstad and Johansson 2011). Water-borne diseases have historically been more prevalent in developing countries and are likely to remain so. Yet climate change could also cause water- and food-borne diseases to become more prevalent in the United States. More frequent and intense rainfall and storm surge events could lead to combined sewer overflows that can contaminate water resources (EPA 2016e, IPCC 2014b citing Patz et al. 2008) and changes in streamflow rates can precede diarrheal disease outbreaks like Salmonellosis and Campylobacteriosis (GCRP 2014 citing Harper et al. 2011 and Rizak and Hrudey 2008). Rising CO_2 concentrations will alter incidence and distribution of pests, parasites, and microbes, leading to increases in the use of pesticides and veterinary drugs (EPA 2016e).

Similar to other climate change health impacts, children and the elderly are most vulnerable to serious health consequences from water- and food-borne diseases that could be affected by climate change (GCRP 2014).

Vector-borne Diseases

Climate change, particularly changes in temperatures, could change the range, abundance, and disease-carrying ability of disease vectors such as mosquitos or ticks (EPA 2016e, IPCC 2014b). This, in turn, could affect the prevalence and geographic distribution of diseases such as malaria, dengue fever, Lyme disease, and West Nile virus in human populations. Some of these changes are already occurring, although the interactions between climate changes and actual disease incidence are complex and multifaceted (Altizer et al. 2013).

Studies estimate that even modest warming could lead to increases in malaria transmission (IPCC 2014b citing Alonso et al. 2011 and Pascual et al. 2006), with the largest effects in tropical highland regions such as highlands in Africa and parts of South America and southeast Asia (Caminade et al. 2014). Warmer temperatures could also lead to increases in dengue transmission (Banu et al. 2014, Colón-González et al. 2013). Disease control activities have reduced malaria incidence despite warming temperatures over recent decades (IPCC 2014b citing Stern et al. 2011 and Omumbo et al. 2011). Climate-induced changes, however, could make it even more difficult for the international public health community to combat these diseases. Vector-borne pathogens are expected to emerge or reemerge due to the interactions of climate factors with many other drivers, such as changing land-use patterns. However, the impacts to human disease will be limited by the adaptive capacity of human populations, such as vector control practices or personal protective measures (EPA 2016e).

Ticks can cause tick-borne encephalitis, Lyme disease, Borrelia, and other diseases. In North America, ticks have expanded their habitat northward in the period 1996 to 2004 (IPCC 2014b citing Ogden et al. 2010), though there is no evidence yet of a corresponding change in distribution of tick-borne diseases. Tick-borne diseases are affected by a complex array of social and environmental factors and are thus difficult to attribute to climate change (IPCC 2014b citing Gray et al. 2009).

Vector-borne diseases such as the ones listed above are generally more common in developing countries. However, Lyme disease, dengue fever, West Nile virus, Rocky Mountain spotted fever, plague, and tularemia affect people in North America today (GCRP 2014 citing Mills et al. 2010, Diuk-Wasser et al. 2010, Ogden et al. 2008, Keesing et al. 2009, Centers for Disease Control 2013, Degallier et al. 2010, Johansson et al. 2009, Jury 2008, Kolivras 2010, Lambrechts et al. 2011, Ramos et al. 2008, Gong et al. 2011, Morin and Comrie 2010, Centers for Disease Control 2012, and Nakazawa et al. 2007). Recent research has demonstrated that the range of the Asian Tiger mosquito, a carrier for West Nile virus, could expand in the northeastern United States (Rochlin et al. 2013). Additional research is needed to better understand whether climate change will increase the risk of these diseases and others (e.g., chikungunya, Chagas disease, and Rift Valley fever viruses) in the United States (GCRP 2014).

Cancer

Climate change could alter temperature, precipitation, and cloud cover, which can alter sun exposure behavior and change the risk of ultraviolet (UV) ray-related health outcomes. However, UV exposure is influenced by several factors, and scientists are uncertain whether it will increase or decrease because of climate change. For example, one study estimates that the effective UV dose increases 2 percent for every 1.8°F (1°C) increase in average temperatures (IPCC 2014b citing van der Leun et al. 2008). This was supported by the study's findings that, in the United States, the number of cases of squamous cell carcinoma increased 5.5 percent and basal cell carcinoma increased 2.9 percent for every 1.8°F (1°C) increment in average temperatures (IPCC 2014b citing van der Leun et al. 2008). However, increasing UV exposure can also have some beneficial effects in terms of Vitamin D levels (IPCC 2014b). Further, UV radiation levels are expected to decrease throughout the century because of ozone layer recovery (IPCC 2014b citing Correa et al. 2013), although changing temperatures could also change the amount of time people spend outdoors (IPCC 2014b citing Belanger et al. 2009), further influencing implications for skin cancers.

Indirect Impacts on Health

In addition to the effects outlined above, climate change can influence human health through several indirect mechanisms. For example, climate change could impact agricultural production, lead to higher food prices, or disrupt food distribution by damaging infrastructure through extreme weather events and heat waves (EPA 2016e, IPCC 2014b citing Auffhammer 2011 and Williams and Funk 2011). African maize yields have been shown to decrease by 1 percent for each degree above 86°F (30°C), even under optimal rainfall conditions (IPCC 2014b citing Lobell et al. 2011). Reduced agricultural production and higher food prices both contribute to undernutrition (IPCC 2014b), and the nutritional value of agriculturally important food crops will decrease as rising levels of CO_2 reduce concentrations of protein and essential minerals in plant species (EPA 2016e). Scientists project this impact will be largest in areas that are already food insecure (IPCC 2014b citing Knox et al. 2012). Climate change can also impact nutrition by harming marine food sources—for example, climate change can lead to marine diseases in corals, shellfish, and other seafood, and this affects human health both through reduced food supply and, in some cases, potential disease transmission (Burge et al. 2014).

Climate change can also influence mental health. People may experience adverse mental health outcomes and social impacts from the threat of climate change, the perceived direct experience of climate change, and changes to the local environment (EPA 2016e). Stress, induced by climate change or other factors, can also result in pregnancy-related problems such as pre-term birth, low birth weight, and maternal complications (Harville et al. 2009, GCRP 2014 citing Xiong et al. 2008). Heat can also affect mental health and has been known to increase suicide rates, dementia, and problems for patients with schizophrenia (EPA 2016e; GCRP 2014 citing Bouchama et al. 2007, Bulbena et al. 2006, Deisenhammer 2003, Hansen et al. 2008, Maes et al. 1994, Page et al. 2007, Basu and Samet 2002, Martin-Latry et al. 2007, and Stöllberger et al. 2009).

Climate change can also affect human exposure to toxic chemicals such as arsenic, mercury, dioxins, pesticides, pharmaceuticals, algal toxins, and mycotoxins through several pathways (Balbus et al. 2013). For example, climate change could cause mercury concentrations in fish to increase (EPA 2016e) because increases in temperature could increase mercury mobility (Balbus et al. 2013, GCRP 2014 citing Riget et al. 2010). Finally, climate change could stress water and other natural resources, and lead to conflict (*see* Section 5.5.2.8). Violent conflict can have serious human health consequences.

5.5.2.7.3 Adaptation

As clear from the above, climate change could stress society's ability to manage existing human health risks as well as create additional risks to manage. The scientific community is advancing ways to manage these risks and adapt to the health impacts of climate change. The IPCC (2014b) characterizes three primary ways to adapt: incremental adaptation, transitional adaptation, and transformational adaptation. Incremental adaptation covers improvements to basic public health and healthcare services, such as vaccination programs and post-disaster initiatives (IPCC 2014b). Transitional adaptation refers to policies and measures to actively incorporate climate change considerations, such as vulnerability mapping, while transformational adaptation will involve more drastic system-wide changes and has yet to be implemented in the health sector (IPCC 2014b).

The public health community has identified several potential adaptation strategies to reduce the risks to human health from climate change. Early warning programs, for example, can be cost-effective ways to reduce human health impacts from extreme weather events (GCRP 2014 citing Chokshi and Farley 2012, Kosatsky 2005, Rhodes et al. 2010, and The Community Preventive Services Task Force 2013). Strategies to reduce the urban heat island effect such as cool roofs and increased green space can reduce health risks from extreme heat (GCRP 2014 citing Stone et al. 2010; EPA 2012c; Boumans et al. 2014).

GHG reduction policies can also have health benefits by improving air quality and promoting active transportation, which can reduce rates of obesity, diabetes, and heart disease (GCRP 2014 citing Markandya 2009 and Haines et al. 2009). Models used to estimate the impacts and damages to human health suggest that global efforts to reduce GHG emissions will act to decrease the number of deaths from air quality and extreme temperature as compared to scenarios with no GHG mitigation (EPA 2015g). In addition, health adaptation strategies can have benefits beyond health, although some could also pose risks that will have to be carefully managed (Cheng and Berry 2013). Identifying new and creative ways to continue to improve human health despite climate change is an area of active research.

5.5.2.8 Human Security

This section provides an overview of the recent findings regarding observed and projected impacts of climate change on human security in the United States and globally. IPCC defines human security in the context of climate change as "a condition that exists when the vital core of human lives is protected, and when people have the freedom and capacity to live with dignity" (IPCC 2014b). This section addresses five key dimensions of human security: (1) livelihoods, (2) cultures, (3) migration and mobility, (4) armed conflict, and (5) state integrity and geopolitical rivalry.[59]

5.5.2.8.1 Summary

As there are multiple drivers of human security, it can be difficult to establish direct causation between climate change and impacts on human security. Overall, the research literature finds that climate change has negative impacts on various dimensions of human security, including livelihoods, cultures, migration, and conflict. However, some dimensions of human security are driven more by economic and social forces rather than by climate change (IPCC 2014b).

Climate change can threaten human security in the following ways:

- **Affecting livelihoods:** Climate change can deprive people of immediate basic needs such as food, water, and shelter, or cause longer-term erosion of livelihood assets and human capital, which undermines human security.
- **Compromising cultures:** Climate change can threaten the natural resource base upon which cultures depend, thereby compromising cultural practices and values. Loss of land and displacement has had well-documented negative impacts on cultures and community well-being. Indigenous, local, and traditional forms of knowledge are a major resource to adapt to climate change, but they may not be sufficient to address projected changes in climate.
- **Increasing migration/restricting mobility:** Climate change can increase forced migration. Migrants can be more exposed to climate change impacts in new areas, such as in cities. Lack of mobility increases vulnerability to climate change.
- **Increasing risks of armed conflict:** Several factors that increase the risk of violence within countries, such as low per capita incomes, economic contraction, and inconsistent political institutions, can be sensitive to climate change. As a result, climate change can contribute to increasing conflict risk under certain circumstances. Increases in the risk of conflict abroad can have national security implications for the United States.
- **Compromising state integrity and increasing geopolitical rivalry:** Climate change can impact critical infrastructure such as transport, water, and energy, thereby reducing the ability of countries to provide the conditions necessary for human security. Sea-level rise can threaten the territorial integrity of some countries such as small-island nations. Transboundary impacts of climate change

[59] Information on the national security implications of climate change for the United States is drawn from several recent national security reports, as peer-reviewed studies are unavailable and the issue was not analyzed in detail in the National Climate Assessment because "there are a number of recent unclassified U.S. Department of Defense (DOD) reports and reports of other groups that have rigorously addressed this topic" (GCRP 2014). The reports that were consulted are the Department of Defense's "Quadrennial Defense Review Report" (DOD 2014), the National Research Council's "Climate and Social Stress: Implications for Security Analysis" (NRC 2013a), and the Center for Naval Analyses (CNA) Corporation report, "National Security and the Accelerating Risks of Climate Change" (CNA Corporation 2014), which was researched and written under the direction of 11 retired senior military officers. The 2014 CNA Corporation report is an update of the first report in 2007, "National Security and the Threat of Climate Change" (CNA Corporation 2007). The 2014 CNA Corporation report validates the findings of the previous report and finds that in many cases the risks of climate change are advancing faster than anticipated.

such as loss of sea ice in the Arctic, migration of fish stocks, and changing shared water resources can increase geopolitical tensions. Impacts on U.S. critical infrastructure, potential disputes in the Arctic, and increased risk of conflict over other resources, including those that do not directly involve the United States, can create national security concerns for the United States (IPCC 2014b, DOD 2014, DOD 2015).

5.5.2.8.2 Observed and Projected Climate Impacts

Economic and Livelihood Dimensions

Economic and livelihood security includes access to food, clean water, shelter, employment, and avoidance of direct risks to health. Climate change poses significant risks to all of these aspects and can thereby threaten the economic and livelihood security of individuals or communities (IPCC 2014b).

Climate change can undermine livelihoods through depriving people of immediate basic needs such as food, water, and shelter, or through causing longer-term erosion of livelihood assets and human capabilities (IPCC 2014b). There are well-documented impacts of climate variability and change on agricultural productivity and food insecurity, water stress and scarcity, and destruction of property and residence (IPCC 2014b citing Carter et al. 2007, Leary et al. 2008, Peras et al. 2008, Paavola 2008, and Tang et al. 2009). Climate variability and change can also affect health and education, which will undermine human capital. For example, it is found that "Indian women born during a drought or flood in the 1970s were 19 percent less likely to ever attend primary school, when compared with women of the same age who were not affected by natural disasters" (IPCC 2014b citing UNDP 2007). Projections using a variety of socioeconomic and climate change scenarios suggest an increase in economic and health risks, including loss of lives, increased psychological stress associated with extreme climatic events, and decreased access to natural resources (IPCC 2014b citing Hall et al. 2003, Kainuma et al. 2004, and Doherty and Clayton 2011). These projected increases in climate change impacts will further threaten the economic and livelihood security of vulnerable populations.

In the United States, climate change is increasingly affecting food and water security (*see* Section 5.5.2.4 and 5.5.2.1), human health (*see* Section 5.5.2.7), and infrastructure and settlements (*see* Section 5.5.2.5 and 5.5.2.6). These impacts will have negative implications for the economic and livelihood security of vulnerable groups. Populations that are most at risk include the urban poor and rural and indigenous communities whose livelihoods are highly dependent upon natural resources (GCRP 2014). For example, declining sea ice, permafrost thaw, and more extreme weather and severe storms are causing increasingly risky travel and hunting conditions in Alaska, threatening traditional livelihoods of Alaska Native populations (GCRP 2014 citing Cochran et al. 2013). In Pacific island communities, warmer sea surface temperature is causing coral bleaching and affecting subsistence fisheries, which undermines traditional livelihoods and raises food security concerns (GCRP 2014 citing Maclellan 2009).

Cultural Dimensions

Climate change can compromise cultural values and practices through its impacts on livelihoods and settlements. Research has documented the impact of changes in natural resources due to changing climatic conditions on rural livelihoods and, therefore, on cultures (IPCC 2014b). Many anthropological studies indicate that further significant changes in the natural resource base would negatively affect indigenous cultures (IPCC 2014b citing Crate 2008, Gregory and Trousdale 2009, and Jacka 2009). Climate change can also cause loss of land and displacement, such as in small island nations or coastal communities, which has well-documented negative cultural and well-being impacts (IPCC 2014b citing Bronen 2011, Johnson 2012, Arnall 2013, Bronen 2010, Bronen and Chapin 2013, and Cunsolo-Willox et al. 2012, 2013).

Cultural values and expressions are dynamic and hence inherently adaptable, and a number of studies have presented examples of cultures that persisted through significant historical upheavals (IPCC 2014b citing Nuttall 2009, Cameron 2012, and Strauss 2012). While adaptation is possible to avoid some losses of cultural assets and expressions, cultural integrity will still be compromised if climate change erodes livelihoods, sense of place, and traditional practices (IPCC 2014b).

The 400 million indigenous people worldwide are the world's greatest reserve of cultural diversity (IPCC 2014b). However, around the world it is increasingly challenging for indigenous communities to maintain cultures, livelihoods, and traditional food sources in the face of climate change (IPCC 2014b citing Crate and Nuttall 2009, Rybråten and Hovelsrud 2010; GCRP 2014 citing Lynn et al. 2013). For example, declining sea ice is causing dangerous travel conditions and reducing access to traditional food in the Arctic (IPCC 2014b citing Ford et al. 2008, Ford et al. 2009, and Hovelsrud et al. 2011). In addition, traditional practices are already facing multiple stressors, such as changing socioeconomic conditions and globalization, which undermines their ability to adapt to climate change (IPCC 2014b citing Green el al. 2010).

The impacts of climate change on traditional practices and cultures are projected to vary across societies, depending on cultural and social resilience. Research has documented that "the efficacy of traditional practices can be eroded when governments relocate communities (IPCC 2014b citing Hitchcock 2009, McNeeley 2012, and Maldonado et al. 2013); if policy and disaster relief creates dependencies (IPCC 2014b citing Wenzel 2009, Fernández-Giménez et al. 2012); in circumstances of inadequate entitlements, rights and inequality (IPCC 2014b citing Shah and Sajitha 2009 and Green et al. 2010; GCRP 2014 citing Lynn et al. 2013); and when there are constraints to the transmission of language and knowledge between generations (IPCC 2014b citing Forbes 2007)" (IPCC 2014b). Lack of involvement in formal government decisionmaking over resources also decreases the resilience of indigenous peoples and their cultures to climate change impacts (IPCC 2014b citing Ellemor 2005, Brown 2009, Finucane 2009, Turner and Clifton 2009, Sánchez-Cortés and Chavero 2011, and Maldonado et al. 2013).

Local and traditional knowledge is a valuable source of information for adapting to climate change (IPCC 2014b, GCRP 2014). There is high agreement in the literature that the integration of local and traditional and scientific knowledge increases adaptive capacity (IPCC 2014b citing Kofinas 2002, Oberthür et al. 2004, Tyler et al. 2007, Anderson et al. 2007, Vogel et al. 2007, West et al. 2008, Armitage et al. 2011, Frazier et al. 2010, Marfai et al. 2008, Flint et al. 2011, Ravera et al. 2011, Nakashima et al. 2012, and Eira et al. 2013). While being an important resource for adaptation, traditional knowledge may not be sufficient to respond to rapidly changing ecological conditions or unexpected or infrequent risks (IPCC 2014b, GCRP 2014). As a result, current traditional knowledge strategies may be inadequate to manage projected climate changes (IPCC 2014b citing Wittrock et al. 2011).

In the United States, climate change is posing particular threats to indigenous populations' traditional livelihoods and cultures, which are closely tied to the natural world. For example, climate change is causing changes in the range and abundance of culturally important plant and animal species, reducing the availability and access to traditional foods, and increasing damage to tribal homes and cultural sites (GCRP 2014 citing Lynn et al. 2013, Voggesser et al. 2013, and Karuk Tribe 2010). In parts of Alaska, Louisiana, the Pacific Islands, and other coastal locations, climate change is already forcing indigenous peoples to relocate from their historical homelands, with negative impacts on their cultures and identities (GCRP 2014). These impacts are projected to become more severe with further changes in natural resources due to climate change.

Migration and Mobility Dimensions

Climate change can increase migration through extreme events or long-term environmental changes. Much of the literature reviewed in the IPCC Special Report on Extreme Events (IPCC SREX) suggests that an increase in the incidence and/or severity of extreme events due to climate change will directly increase the risks of displacement and amplify its impacts on human security (IPCC 2014b). Climate change-induced mass migration threatens to adversely affect the humanitarian assistance requirements of the U.S. military, as well as strain its ability to respond to conflict (NRC 2011c). Displacement affects human security by impacting housing, health, and economic outcomes (IPCC 2014b citing Adams et al. 2009 and Hori and Shafer 2010).

Major extreme weather events have in the past led to significant population displacement (IPCC 2014b). However, such displacement is usually short-term, and most displaced people try to return to their original residence and rebuild as soon as circumstances allow (IPCC 2014b). As a result, only a proportion of displacement leads to more permanent migration (IPCC 2014b citing Foresight 2011 and Hallegatte 2012). For example, the Pakistan floods of 2010 resulted in primarily localized displacement rather than longer-term migration (IPCC 2014b citing Gaurav et al. 2011). Fussell et al. (2014) found that the population in New Orleans recovered gradually after Hurricane Katrina, reaching about half of its pre-Katrina size by mid-2006 and about three-quarters by mid-2012. These populations included both returning households and new immigrant households, and anecdotal evidence indicated that most were returning residents. The study also found that much of the in-migration after Hurricane Katrina was from nearby, less affected counties.

However, extreme events can sometimes be associated with immobility or in-migration instead of displacement. For example, Paul (2005) found that little displacement occurred following floods in Bangladesh and there was in-migration due to reconstruction activities (IPCC 2014b citing Paul 2005). Additionally, there is some evidence that climate change can reduce migration flows due to its impacts on productivity. As migration is resource-intensive, in some cases migration flows decreased when the households had limited resources, such as in drought years (IPCC 2014b citing Findley 1994, van der Geest 2011, and Henry et al. 2004).

Lack of mobility is associated with increased vulnerability to climate change, as vulnerable populations frequently do not have the resources to migrate from areas exposed to the risks from extreme events. When migration occurs among vulnerable populations, it is usually an “emergency response that creates conditions of debt and increased vulnerability, rather than reducing them” (IPCC 2014b citing Warner and Afifi 2013). Migration and mobility outcomes can also vary based on socioeconomic and demographic factors, as seen in the high differentiation by income, race, class, and ethnicity in emergency evacuation responses and return migration after Hurricane Katrina (IPCC 2014b citing Elliott and Pais 2006, Falk et al. 2006, and Landry et al. 2007).

A number of studies have found that migrants can face increased risks to climate change impacts in their new destinations, such as in cities (IPCC 2014b citing Black et al. 2011). For example, migrants in Buenos Aires, Lagos, Mumbai, and Dakar are often located in areas at higher risks to extreme events than long-term residents (IPCC 2014b citing World Bank 2010b and Mehrotra et al. 2011). Other studies in Shanghai and the Cayman Islands found that migrants have less knowledge about and are least likely to prepare for tropical storms (IPCC 2014b citing Wang et al. 2012 and Tompkins et al. 2009).

Simulation studies show that long-term environmental changes, sea-level rise, coastal erosion, and loss of agricultural productivity due to climate change will significantly affect migration flows (IPCC 2014b citing Lilleor and Van den Broeck 2011). These changes can amplify existing migration trends such as rural-to-urban migration. For example, some studies found that increased temperatures and drier conditions would reduce crop yield and increase the rate of emigration from Mexico to the United States (Oswald-Spring et al. 2014, IPCC 2014b citing Feng et al. 2010). Another study modelled internal migration rates within Brazil and found that the projected warming and drying trends would increase out-migration from rural areas (IPCC 2014b citing Barbieri et al. 2010).

Sea-level rise, coastal inundation, coastal erosion, and permafrost melting can lead to permanent displacements. Nicholls et al. (2011) estimated that with no adaptation investment, a 0.5-meter (1.6-foot) sea-level rise would *likely* imply the displacement of 72 million people; a 2.0-meter (6.5-foot) sea-level rise would *likely* displace 187 million people, mostly in Asia (IPCC 2014b citing Nicholls et al. 2011). Curtis and Schneider (2011) projected that 20 million people in the United States would be dislocated by sea-level rise by 2030 in four major coastal areas (northern California, New Jersey, South Carolina, and southern Florida). The study defined "at-risk" locations as those that can be inundated under two worst-case scenarios: 1-meter (3.2-foot) inundation for sea-level rise and 4-meter (13.1-foot) for storm surges/flooding. The impact of future sea-level rise is projected to extend beyond the inundated counties as displaced populations will migrate to other areas in the country (Curtis and Schneider 2011). In Alaska, several coastal villages are experiencing such severe coastal erosion and permafrost thaw that resettlement is the only viable option (IPCC 2014b citing Bronen 2010, Oliver-Smith 2011, and Marino 2012). The NCA reports states that more than 30 indigenous villages in Alaska are "either in need of, or in the process of, relocating their entire village" (GCRP 2014 citing Cochran et al. 2013 and Bender et al. 2011).

However, populations in at-risk areas do not always choose to migrate due to strong ties with their homelands. For example, survey residents on the island of Funafuti, Tuvalu have emphasized place attachment as reasons for not migrating, despite forecasts that the island could become uninhabitable (IPCC 2014b citing Mortreux and Barnett 2009). In another example, pastoralists displaced by a drought in Sudan in the 1990s tried to return to their original settlements after the drought despite conflict and other factors (IPCC 2014b citing Haug 2002). However, if the impacts of climate change become more pronounced, they can be a more significant driver of migration in the future (IPCC 2014b citing Adams and Adger 2013).

<u>Armed Conflict</u>

Most of the research on the relationship between climate change and violent and armed conflict focuses on the link between climate variability and regional or country conflicts in the modern era. Temperature or rainfall variability is used as a proxy for longer term changes that might occur due to climate change (IPCC 2014b). The association between short-term warming and deviations in rainfall (including floods and droughts) with armed conflict is contested, with some studies finding a relationship while others finding no relationship (IPCC 2014b). Most studies find that climate change impacts on armed conflict is negligible in situations where other risk factors are extremely low, such as where per capita incomes are high or governance is effective and stable (IPCC 2014b citing Bernauer et al. 2012, Koubi et al. 2012, Scheffran et al. 2012, and Theisen et al. 2013).

In response to the difficulty of finding direct relationship between climate variability and violence, some research has investigated the impacts of climate change on factors that are known to increase the risk of civil war and other armed conflicts (IPCC 2014b citing Bergholt and Lujala 2012, Koubi et al. 2012). Examples of such factors include a recent history of civil violence, low levels of per capita income, low rates of economic growth, economic shocks, inconsistent political institutions, and the existence of conflict in neighboring countries (IPCC 2014b citing Miguel et al. 2004, Weede 2004, Hegre and Sambanis 2006, Dixon 2009, Blattman and Miguel 2010, and Brückner and Ciccone 2010). As many of these factors are sensitive to climate change, changes in average and extreme climatic conditions can increase conflict risks. For example, climate change could slow economic growth and hinder efforts to raise per capita incomes in certain low income countries, particularly in Africa where the risk of conflict is highest (IPCC citing Mendelsohn et al. 2000, Mendelsohn et al. 2006, Stern 2007, and Eboli et al. 2010). The incidence or severity of extreme events could increase due to climate change, which might cause economic shocks that would potentially increase the risk of violent conflicts (IPCC 2014b citing Bergholt and Lujala 2012, Hallegatte 2012, and Adam 2013). Increased migration due to extreme events or long-term environmental changes could increase the risk of violent conflict, particularly if the destination areas are already under environmental or social stress (IPCC 2014b, NRC 2013a).

A recent study by Gleick et al. (2014) found that water and climatic conditions played a direct role in worsening Syria's economic conditions and contributed to triggering the civil war that began in March 2011. Syria experienced a multi-season, multi-year extreme drought starting in 2006 and lasting into 2011. This drought combined with inefficient water policies and systems in Syria as well as in other countries in the eastern Mediterranean region caused agricultural failures, which contributed to the displacement of populations from rural to urban centers, food insecurity for more than a million people, and increased unemployment in urban areas. Together with other social, religious, and political factors, these conditions led to widespread political unrest and violence. As climate change is expected to exacerbate water scarcity in the region, it would likely increase the risks of local and regional conflict if there are no collective efforts to improve water management and address the impacts of climate change (Gleick 2014, DOD 2015).

In summary, "there is justifiable common concern that climate change or changes in climate variability increases the risk of armed conflict in certain circumstances […] even if the strength of the effect is uncertain" (IPCC 2014b citing Bernauer et al. 2012, Gleditsch 2012, Scheffran et al. 2012, and Hsiang et al. 2013). It is, however, not possible to make confident statements regarding the impacts of future climate change on armed conflict due to the lack of "generally supported theories and evidence about causality" (IPCC 2014b).

The significant reductions in Arctic sea ice coverage resulting from climate change have increased the maritime availability of the region—both through the reduction of sea ice coverage and the disappearance of multi-year ice accumulation. Some estimates suggest a continued decline of Arctic summer sea ice at the current rate of 10 percent per decade, facilitating cross-Arctic transit by 2030 (NRC 2011b). This increased accessibility threatens to increase competition between nations over new sources of petroleum, natural gas, and non-fuel minerals (NRC 2011b). The Arctic region plays host to a variety of maritime boundary disputes that may be exacerbated by the increased accessibility of the region due to warmer temperatures—such as the status of Canada's Northwest Passage. Furthermore, bordering nations maintain unresolved sea and economic zone disputes in the Arctic (NRC 2011b).

The potential impacts of climate change on accelerating instability in volatile regions of the world have profound implications for national security of the United States. The DOD 2014 Quadrennial Defense Review indicates that the projected effects of climate change "… are threat multipliers that will aggravate stressors abroad such as poverty, environmental degradation, political instability, and social tensions—conditions that can enable terrorist activity and other forms of violence" (DOD 2014).

<u>State Integrity and Geopolitical Rivalry</u>

Climate change can compromise state integrity by affecting critical infrastructure, threatening territorial integrity, and increasing geopolitical rivalry (IPCC 2014b). Climate change and extreme weather events are already affecting critical infrastructure such as water and sanitation, energy, and transportation in the United States and globally, and these impacts are projected to increase with further changes in climate (*see* Sections 5.5.2.5 and 5.5.2.6). Climate change impacts on critical infrastructure will reduce the ability of countries to provide the economic and social services that are important to human security (IPCC 2014b). Climate change can also affect military logistics, energy, water, and transportation systems, compromising the ability of the U.S. military to conduct its missions (NRC 2011c, CNA Corporation 2014, NRC 2013a). Furthermore, the U.S. military could become overextended as it responds to extreme weather events and natural disasters at home and abroad, as along with current or future national security threats (NRC 2011c, CNA Corporation 2014).

Sea-level rise, storm surge, and coastal erosion can threaten the territorial integrity of small island nations or countries with significant areas of soft low-lying coasts (IPCC 2014b citing Hanson et al. 2011, Nicholls et al. 2011, Barnett and Adger 2003, and Houghton et al. 2010). Accelerating sea ice loss in the Arctic can open access to resources and allow new shipping routes, potentially increasing security concerns as a result of territorial and maritime disputes if equitable arrangements between countries cannot be agreed to (IPCC 2014b, GCRP 2014). Other transboundary impacts of climate change such as changing shared water resources and migration of fish stocks can also increase geopolitical rivalry among states (IPCC 2014b). Additionally, climate change could increase tension and instability over energy supplies (CNA Corporation 2014). The presence of robust interstate institutions to manage disputes is critical to reducing the risk of conflict (IPCC 2014b).

5.5.2.8.3 Adaptation

Adaptation strategies can reduce vulnerability and thereby increase human security. Examples of adaptation measures to improve livelihoods and well-being include diversification of income-generating activities in agricultural and fishing systems, development of insurance systems, and provision of education for women. Integration of local and traditional knowledge is found to increase the effectiveness of adaptation strategies. Improvements in entitlements and rights, as well as engagement of indigenous peoples in decisionmaking, increase their social and cultural resilience to climate change (IPCC 2014b).

There is not enough evidence on the effectiveness of migration and resettlement as adaptation. Migration is costly and disruptive and is thus often perceived as an adaptation of last resort (IPCC 2014b citing McLeman 2009). Bronen and Chapin (2013) argue that the “legitimacy and success [of relocation] depend on incorporating cultural and psychological factors in the planning processes” (IPCC 2014b). In the United States, new governance institutions, frameworks, and funding mechanisms are needed to support the relocation processes of communities displaced by climate change (GCRP 2014).

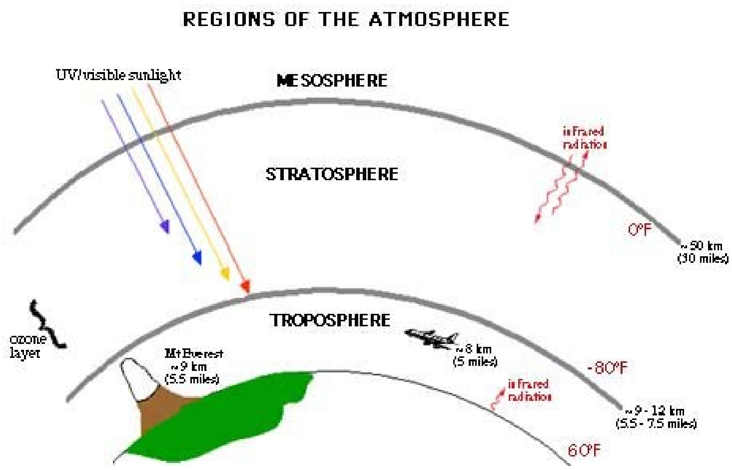
Poorly designed adaptation strategies can increase the risk of conflict and amplify vulnerabilities in certain populations, if they exacerbate existing inequalities or grievances over resources (IPCC 2014b). As a result, it is important to consider differentiated vulnerabilities and the potential impact of adaptation on conflict. In addition, investments in institutions to resolve conflicts over resources by peaceful means are critical to enhancing human security at all levels (IPCC 2014b). Recognizing the risks climate change poses to national security, the DOD is now incorporating the consequences of climate change in its long-range strategic plans, including potential impacts on its facilities and missions (DOD 2014).

5.5.2.9 Carbon Dioxide and Climate Change Impacts on Stratospheric Ozone

This subsection presents a review of stratospheric ozone and describes how CO_2 and climate change are projected to affect stratospheric ozone concentrations. As this topic is not addressed in the recently-released IPCC or NCA reports, this section primarily draws from journal articles and panel-reviewed reports.

Ozone in Earth's stratosphere (the upper layer of the atmosphere) absorbs some harmful UV radiation from the Sun, and therefore protects humans and other organisms (*see* Figure 5.5.2-1). Since the 1980s, satellite and ground observations have shown reductions in the concentrations of stratospheric ozone. There is an international consensus that human-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 emissions of these substances (Fahey and Hegglin 2011). In response to these efforts, the rate of stratospheric ozone reduction has slowed. Although there are elements of uncertainty, stratospheric ozone concentrations are projected to recover to pre-1980 levels over the next several decades (Fahey and Hegglin 2011, WMO 2011), with further "thickening" of the ozone layer possible by 2100 in response to climate change (IPCC 2014b citing Correa et al. 2013).

Figure 5.5.2-1. The Three Lowest Layers in Earth's Atmosphere and the Location of the Ozone Layer



Source: NOAA 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 polar stratospheric clouds that are responsible for accelerated ozone depletion. Climate change could enhance atmospheric circulation patterns that affect stratospheric ozone concentrations, 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 summary, 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 CCSP (2008) report, *Trends in Emissions of Ozone-depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure* (CCSP 2008b). These resources remain the best available summaries of climate impacts on stratospheric ozone.

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).[60] 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 impacts (Fahey and Hegglin 2011, Fahey et al. 2008).

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 nanometers (Fahey and Hegglin 2011). Ozone, which is a very reactive molecule, could 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. Changes in climate affect many of these factors, as described in Sections 5.5.2.9.1 through 5.5.2.9.3.

5.5.2.9.1 Human-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 human-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.[61]

In 1987, an international agreement, the Montreal Protocol on Substances that Deplete the Ozone Layer, was established to reduce the consumption and production of human-made ozone-depleting substances in order to protect and heal the ozone layer and rebuild the ozone hole.[62] 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.

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[60] 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.

[61] For example, when a 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).

[62] 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.

Increases in the emissions of other trace gases (e.g., CH_4 and N_2O) and CO_2 affect stratospheric ozone concentrations (Fahey et al. 2008). When CH_4 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; the impact on stratospheric ozone is discussed below.

5.5.2.9.2 Changes in Atmospheric Temperature

Since the observational record began in the 1960s, global stratospheric temperatures have been decreasing in response to ozone depletion, increased tropospheric CO_2, and changes in water vapor (Fahey et al. 2008). Natural concentrations of 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). This is supported by a recent study that used a chemistry-climate model to simulate changes in ozone observed over the past century and found the rate of ozone loss reduced in the upper stratosphere due to cooling temperatures (Reader et al. 2013).

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.

5.5.2.9.3 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. Over the past century, it was been suggested that the ozone in the lower stratosphere has experienced an acceleration in this transport, particularly in the northern hemisphere—potentially explaining the larger increase in total atmospheric ozone per area (i.e., column ozone) observed in the northern hemisphere compared to the southern hemisphere (Reader et al. 2013).

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).[63] 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 affect surface climate parameters.

5.5.2.9.4 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 -0.15 to 0.05 watts per square meter, although there is great uncertainty in this estimate (Ravishankara et al. 2008).

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 (A1B) emissions scenario, 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 and 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 as a result of 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 increase per decade in the annual mean troposphere-to-stratosphere exchange rate. This acceleration could affect long-lived gases such as CFCs, CH_4, and N_2O 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).

[63] 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).

5.5.2.10 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.[64] 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, when the tipping point is crossed. 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; rapid releases of CH_4 to the atmosphere from undersea hydrates or melting permafrost; and large-scale changes in precipitation and the hydrologic cycle.

5.5.2.10.1 Atlantic Meridional Overturning Circulation

The AMOC is the northward flow of warm, salty water in the upper layers of the Atlantic Ocean coupled to the southward flow of colder water in the deep layers, and transports oceanic heat from low to high latitudes.

The term thermohaline circulation (THC) refers to the physical driving mechanism of ocean circulation, resulting from fluxes of heat and freshwater across the sea surface, subsequent interior mixing of heat and salt, and geothermal heat sources. The AMOC discussed in the IPCC reports is the observed response in the Atlantic Ocean basin to this type of ocean circulation coupled with wind-driven currents. If enough freshwater enters the North Atlantic (such as from melting sea ice or the Greenland ice sheet), the density-driven sinking of North Atlantic waters might be reduced or even stopped, as apparently occurred during the last glacial cycle (Lenton et al. 2008 citing Stocker and Wright 1991). This would likely reduce the northward flow of thermal energy in the Gulf Stream and result in less heat transport to the North Atlantic. At the same time, reduced formation of very cold water would likely slow the global ocean THC, leading to impacts on global climate and ocean currents.

It is *very likely* that the AMOC will weaken over the 21st century;[65] it is *likely* that there will be some decline in the AMOC by about 2050, but there could be some decades when the AMOC increases due to large natural internal variability (IPCC 2013a). It is *very unlikely* that the AMOC will undergo an abrupt transition or collapse in the 21st century (for the scenarios considered); and that there is *low confidence* in assessing the evolution of the AMOC beyond the 21st century because of the limited number of analyses and equivocal results (IPCC 2013a). However, the SPM concludes that a collapse beyond the 21st century for large sustained warming cannot be excluded.

This finding is supported by an NRC synthesis study of recent information on tipping points and abrupt climate change. The study committee found that the AMOC is likely to remain stable to disturbances and that an abrupt change or shut down will not occur in this century. The report acknowledged the importance of ongoing monitoring to identify whether slow changes in the AMOC have important

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[64] In the 2013 report, *Abrupt Impacts of Climate Change*, NRC also included a discussion on abrupt changes in physical, biological, and human systems that result from gradual climate change (referred to as "abrupt climate impacts", as opposed to "abrupt climate changes"). The discussion in this section remains focused on abrupt climate changes, while the effect of abrupt impacts is discussed further in separate sub-sections of Section 5.5.2.10.6.

[65] Best estimates and ranges for the AMOC reduction are 11 percent (1 to 24 percent) in the lowest (RCP2.6) scenario and 34 percent (12 to 54 percent) in the highest (RCP8.5) scenario (IPCC 2013b).

effects, and to better understand the slight possibility of a major event occurring, such as shut down of the AMOC (NRC 2013b).

5.5.2.10.2 Greenland and West Antarctic Ice Sheets

The sustained mass loss by ice sheets would cause large sea-level rise, and some part of the mass loss might be irreversible (IPCC 2013a). For example, there is *high confidence* that sustained warming greater than some threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea-level rise of up to 7 meters (29 feet). Current estimates indicate that the threshold is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) global mean warming with respect to pre-industrial.

Of particular concern is the potential for abrupt increases in sea-level rise from rapid destabilization and ice loss from glaciers with bases in deep water. For these glaciers, warming oceans erode the base and cause the ice to float, accelerating losses. In Greenland, most areas of deep water contact between ice sheets and the ocean are limited to narrow troughs where the ice is less likely to flow rapidly into ocean basins, so the likelihood of rapid destabilization during this century is low (NRC 2013b).

Abrupt and irreversible ice loss from a potential instability of marine-based (as opposed to land-based) sectors of the Antarctic ice sheet (i.e., ice shelves) in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment (IPCC 2013a, NRC 2013b, Hansen et al. 2013). That said, two recent studies (Joughin et al. 2014, Rignot et al. 2014) published since the IPCC (2013b) assessment report indicate that these Western Antarctic ice shelves have been accelerating their melt in recent decades, that this increase is projected to continue, and that there is little in the regional geography to stop them from an eventual full decline (i.e., an irreversible collapse) as they retreat into deeper water.

A recent study by Mengel and Levermann (2014) demonstrated the potential irreversibility of marine-based ice sheet loss and the presence of thresholds beyond which ice loss becomes self-sustaining. In a study of ice in the Wilkes Basin of East Antarctica (as opposed to West Antarctic ice sheets, which have been studied in more detail), the authors found that the loss of a relatively small volume of ice in a seaward region of the shelf (dubbed the “ice plug” by the authors) would lead to an irreversible disintegration of the entire regional ice sheet. There is no short-term threat of ice loss from the Wilkes Bay ice sheet, as the study looked at scenarios of 400 to 800 years with ocean temperatures 1 to 2.5°C (1.8 to 4.5°F) warmer than current conditions.

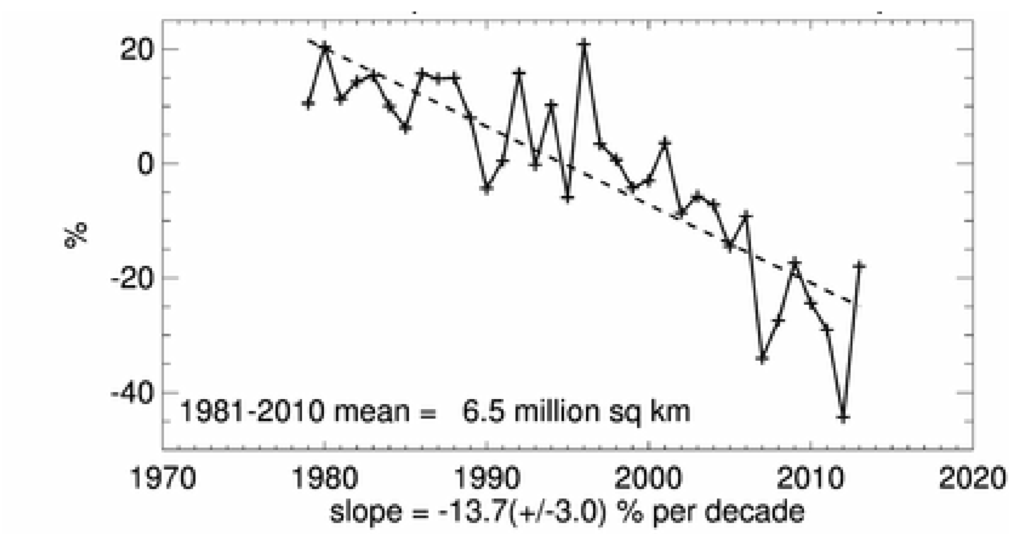
5.5.2.10.3 Arctic Sea Ice

Since satellite observations of Arctic sea ice began in 1978, a significant decline in the extent of summer sea ice[66] has been observed, with the record minimum extent—a decrease of more than 40 percent in September, i.e., the month when the minimum in the sea-ice extent typically occurs—recorded in 2012 (*see* Figure 5.5.2-2) (GCRP 2014 citing NSIDC 2012). There is robust evidence that the downward trend in Arctic summer sea-ice extent since 1979 is now reproduced by more models than at the time of the AR4, with about one-quarter of the models showing a trend as large as, or larger than, the trend in the

[66] 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, and vice versa. For example, 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 could contribute to thinner or less ice in a following season).

observations. Most models simulate a small downward trend in Antarctic sea-ice extent, albeit with large inter-model spread, in contrast to the small upward trend in observations (IPCC 2013a). The IPCC (2013a) suggests that anthropogenic influences have *very likely* contributed to these Arctic sea ice loss since 1979, and that it is *very likely* that the Arctic sea ice cover will continue to shrink and thin.

Figure 5.5.2-2. Northern Hemisphere Extent Anomalies[a,b]



[a] Source: GCRP 2014 citing NSIDC 2014.

[b] Monthly ice extent anomalies plotted as a time series of percent difference between the extent for September and the mean for September based on the January 1981 to December 2010 data. The anomaly data points are plotted as plus signs and the trend line is plotted with a dashed gray line.

Rising temperatures are reducing ice volume and surface extent on land, lakes, and sea with this loss of ice expected to continue. Arctic sea-ice extent increases during the cold winter and decreases during the warmer summer. The Arctic Ocean is expected to become essentially ice free in summer before mid-century under future scenarios that assume continued growth in global emissions, although sea ice would still form in winter (GCRP 2012 citing Stroeve et al. 2012b and Wang and Overland 2009; NRC 2013b). Year-round reductions in Arctic sea-ice extent are projected by the end of the 21st century from multi-model averages. These reductions range from 43 percent for the lower (RCP2.6) scenario to 94 percent for the higher (RCP8.5) scenario in September and from 8 percent for the lower (RCP2.6) scenario to 34 percent for the higher (RCP8.5) scenario in February (*medium confidence*) (IPCC 2013a). Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea-ice extent, a nearly ice-free Arctic Ocean in September before mid-century is *likely* for the higher (RCP8.5) scenario (*medium confidence*). A projection of when the Arctic might become nearly ice free in September in the 21st century cannot be made with confidence for the other scenarios (IPCC 2013a).

Larger areas of open water in the Arctic during the summer will affect the Arctic climate, ecosystems, and human activities in the North; these effects on the Arctic could potentially be large and irreversible. Less summer ice may disrupt the marine food cycle, alter the habitat of certain marine mammals, and exacerbate coastline erosion. Reductions in summer sea ice will also increase the navigability of Arctic waters, opening up opportunities for shipping and economic activities, but also creating new political and legal challenges among circumpolar nations (NRC 2013b).

5.5.2.10.4 Irreversibility of Anthropogenic Climate Change Resulting From CO_2 Emissions

A large fraction of anthropogenic climate change resulting from CO_2 emissions (e.g., global mean temperature increase, and ocean acidification increase) is irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period (IPCC 2013a). Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. Due to the long time scales of heat transfer from the ocean surface to depth, ocean warming will continue for centuries. Depending on the scenario, about 15 to 40 percent of emitted CO_2 will remain in the atmosphere longer than 1,000 years (IPCC 2013b). In addition, the following impacts have been estimated per 1°C (1.8°F) of global warming: 5 to 10 percent change in precipitation for a number of regions, 3 to 10 percent increase in heavy rainfall, 5 to 15 percent yield reductions of a number of crops, and 5 to 10 percent change in streamflow in many river basins worldwide (NRC 2011b).

5.5.2.10.5 Increases in the Risk of Extinction for Marine and Terrestrial Species

The rate of climate change is increasing the risk of extinction for a number of marine and terrestrial species (NRC 2013b). Climate change can cause abrupt and irreversible extinctions through four known mechanisms (NRC 2013b):

- Direct impacts from an abrupt event, such as flooding of an ecosystem through a combination of storm surge and sea-level rise.
- Incremental climatic changes that exceed a threshold beyond which a species enters decline, for example, pikas and ocean coral populations are close to physiological thermal limits.
- Adding stress to species in addition to non-climatic pressures such as habitat fragmentation, overharvesting, and eutrophication.
- Biotic interactions, such as increases in disease or pests, loss of partner species that support a different species, or disruptions in foodwebs after the decline of a keystone species.

It is very likely that some species will become extinct or fall below viable numbers in the next few decades (NRC 2013b). Vulnerable species include species whose tolerance to climate parameters will be exceeded by climate change, species whose processes of growth, reproduction, or survival will be affected by climate change (including biotic interactions), and species trapped by habitat fragmentation in areas that will become unsuitable (NRC 2013b). Based on the current state of scientific knowledge, *Abrupt Climate Change Impacts* (NRC 2013b) concluded that there is a “plausible” risk that already-elevated extinction rates will be accelerated further by climate change. The outcome would be a loss of “many more” species over the next few decades than would occur without climate change, although it is not possible to develop exact probabilities of the added contribution of climate change to extinction risk (NRC 2013b).

5.5.2.10.6 Additional Tipping Points

There is no clear scientific consensus at this time as to whether major tipping points, other than loss of the Arctic sea ice in summer and increases in the risk of extinction of marine and terrestrial species, will be reached during this century (GCRP 2014, NRC 2013b).

The *National Climate Assessment* (GCRP 2014) and *Abrupt Impacts of Climate Change* (NRC 2013b) indicate a number of potential tipping points (*see* Figure 5.5.2-3) including:

- Arctic sea ice (*see* above)
- Greenland ice sheet (*see* above)
- West Antarctic ice sheet (*see* above)
- El-Niño-Southern Oscillation (ENSO)
- Indian summer monsoon
- West African monsoon
- Amazon rainforest
- Boreal forest
- Atlantic Meridional Overturning Circulation (AMOC) (*see* above)
- Release of methane hydrates and permafrost and tundra loss

El-Niño-Southern Oscillation (ENSO):[67] The changes that might lead to increasingly persistent (and frequent) El Niño (or La Niña) conditions are particularly uncertain. Increases in ocean heat content could have an impact on ENSO conditions, but predictive and paleoclimate modeling studies do not agree on the magnitude, frequency, and direction of these impacts. However, ENSO has substantial and large-scale impacts on the global climate system (Lenton et al. 2008).[68]

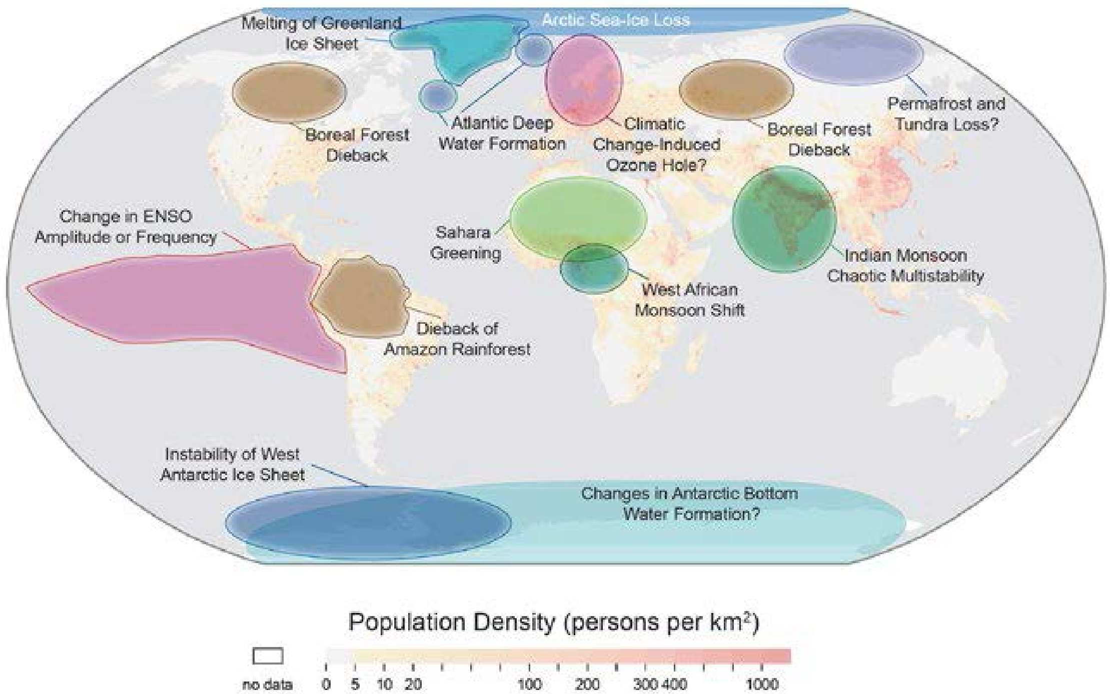
Indian Summer Monsoon: The Indian summer monsoon is the result of land-to-ocean pressure gradients and advection of moisture from ocean to land. By warming the land more than the ocean, climate change generally strengthens the monsoon. However, reductions in the amount of solar radiation that is absorbed by the land surface, due to some types of land use change, generally weaken it. An albedo greater than roughly 50 percent is necessary to simulate the collapse of the Indian summer monsoon in a simple model (Lenton et al. 2008 citing Zickfeld et al. 2005). IPCC projections do not project passing a threshold this century, although paleoclimatic reconstructions do indicate that the monsoon has changed substantially in the past (Lenton et al. 2008).

West African Monsoon: Sahara/Sahel rainfall depends on the West African monsoon circulation, which is affected by sea-surface temperature. By warming the land more than the ocean and therefore causing greater upward movement of the air, GHG forcing is expected to draw more moist oceanic air inland and thereby increase rainfall in the region, which is simulated by some models. Other models, however, project a less productive monsoon. The reasons for this inconsistency are not clear (Lenton et al. 2008).

[67] ENSO describes the full range of the Southern Oscillation (see-saw of atmospheric mass or pressure between the Pacific and Indo–Australian regions) that includes both sea-surface temperature increases and decreases compared to the long-term average. El Niño is the warm phase of ENSO, in which sea surface temperatures along the central and eastern equatorial Pacific are warmer than normal, while La Niña is the cold phase of ENSO.

[68] ENSO influences patterns of tropical sea surface temperature, and has been implicated in historical episodes of extreme drought, including the "mega-droughts" (900 to 1600 AD).

Figure 5.5.2-3. Potential Tipping Points[a,b]



[a] Source: GCRP 2014 adapted from Lenton et al. 2008.

[b] Stylized map of potential policy-relevant tipping elements in the Earth's climate system overlain on population density. Question marks indicate systems whose status as tipping elements is particularly uncertain.

Amazon Rainforest: The recycling of precipitation in the Amazon rainforest implies that deforestation, reductions in precipitation, a longer dry season, and increased summer temperature could contribute to forest dieback. These conditions are thought to be linked to a more persistent El Niño and an increase of global average temperature by 3 to 4°C (5.4 to 7.2°F). Important additional stressors also present include forest fires and human activity (such as land clearing). A critical threshold might exist in canopy cover, which could be reached through changes in land use or regional precipitation, ENSO variability, and global radiative forcing (Lenton et al. 2008).

Boreal Forest: The dieback of boreal forest could result from a combination of increased heat stress and water stress, leading to decreased reproduction rates, increased disease vulnerability, and subsequent fire. Although highly uncertain, studies suggest a global warming of 3°C (5.4°F) could be the threshold for loss of the boreal forest (Lenton et al. 2008).

Release of Methane Hydrates and Permafrost and Tundra Loss: A "catastrophic" release of methane to the atmosphere from clathrate hydrates[69] in the sea bed and permafrost, and from northern high-latitude and tropical wetlands, has been identified as a potential cause of abrupt climate change (EPA

[69] Clathrate hydrates are "inclusion compounds" in which a hydrogen-bonded water framework—the host lattice—traps "guest" molecules (typically gases) within ice cages. Naturally occurring gas hydrate on Earth is primarily methane hydrate and forms under high pressure–low temperature conditions in the presence of sufficient methane. These conditions are most often found in relatively shallow marine sediments on continental margins, but also in some high-latitude terrestrial sediments (permafrost). Although the amount of methane stored as hydrate in geological reservoirs is not well quantified, it is very likely that very large amounts are sequestered in comparison to the present total atmospheric methane burden (GCRP 2014 citing Brook et al. 2008).

2009, Hansen et al. 2013). Clark et al. (2008) state that the size of the hydrate reservoir is uncertain (perhaps by up to a factor of 10), making judgments about risk difficult to assess (EPA 2009).

This uncertainty is borne out by a study by Tanocai et al. (2009) estimating soil organic carbon pools in the northern circumpolar permafrost regions. The study reports new estimates—including deeper layers and pools not previously accounted for—about double those reported in previous analyses for the first meter of soil. Hansen et al. (2013), while recognizing that the risk of triggering rapid methane hydrate or permafrost emissions is largely unquantified, observed that hydrates under shallow waters are most vulnerable to release. Larger deposits in deep sediments are likely to remain stable for millennia. The timescale for release of methane and CO_2 emissions from terrestrial permafrost in response to warming is between a few decades and several centuries if warming continues (Hansen et al. 2013).

The outlook for an abrupt, irreversible release of CO_2 and methane from terrestrial permafrost and methane hydrates in this century is judged to be low, with a moderate risk of significant change in the stability of methane hydrates and a high risk for terrestrial permafrost after 2100 (NRC 2013b). An abrupt release of these stocks could contribute to sudden, dramatic warming in the atmosphere; it is possible, for example, that sudden releases from methane hydrates and frozen soils have contributed to "hyper thermals" or sudden spikes in global warming that have occurred alongside slower, gradual warming trends in the past (Hansen et al. 2013).

To the degree that the Final Action reduces the rate of CO_2 emissions, it contributes to the general reduction or delay of reaching these tipping-point thresholds. Moreover, while this rulemaking alone does not produce sufficient CO_2 emissions reductions to avoid reaching these tipping-point thresholds, it is one of several federal programs that, together, could make substantial contributions in averting levels of abrupt and severe climate change.

5.5.3 Regional Impacts of Climate Change

This section discusses the regional impacts of climate change in the United States and is a supplement to the discussions of sectoral impacts provided previously. Specifically, Sections 5.5.2.1 through 5.5.2.8 address cumulative impacts on key natural and human resources by region (Northeast, Southeast and the Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, and the Islands [i.e., Hawaii and the U.S. affiliated Pacific Islands]). In addition, a section discussing impacts on indigenous peoples is provided. Each section begins with a brief description of observed and projected environmental change and then discusses impacts on the following sectors: freshwater resources; ocean systems, coastal, and low-lying areas; food, fiber, and forest products; terrestrial and freshwater ecosystems; urban areas; rural areas; human health; and human security.

Although this section does not present specific examples of adaptation to climate impacts in each region or sector, adaptation is occurring at local, state, and regional scales. A number of organizations, state agencies, and planning bodies are considering adaptation options in response to climate change and climate variability. Across resources and regions, the process of incorporating adaptation into decisionmaking varies according to, for example, the awareness, frequency and severity of the climate change impacts. For some examples of general adaptation efforts at varying geographic scales, *see* the adaptation sections in each resource-sector discussion in Section 5.5.2.

5.5.3.1 Northeast

This section discusses climate change impacts in the Northeast region of the United States, which includes the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

The Northeast is vulnerable to a variety of climate change impacts, including increasing temperatures, shorter snow seasons, more frequent heat waves, sea-level rise, drought, coastal and riverine flooding, and intense precipitation events. Climate change is projected to exacerbate each of these impacts, which can result in changes to the area's economy, landscape, and quality of life (GCRP 2014). In particular, the Northeast is vulnerable to impacts on human health; food, fiber, and forest products; ocean systems, coastal, and low-lying areas; urban areas; and rural areas.

5.5.3.1.1 Observed and Projected Changes in Exposure

Increasing temperatures have already had wide-ranging impacts on the Northeast. Between 1895 and 2011, the annual average temperature in the Northeast has risen almost 2.0°F at an average rate of nearly 0.16°F per decade (GCRP 2014 citing Kunkel et al. 2013a). Winter temperatures have risen 50 percent faster than the annual average, at nearly 0.24°F per decade over the same time period (Kunkel et al. 2013a).

Temperatures are projected to continue to rise. By the 2080s, Northeast temperatures are projected to increase by 4.5 to 10°F under the higher (A2) emissions scenario, and 3 to 6°F under the lower (B1) emissions scenario, relative to the 1971 to 1999 period (GCRP 2014 citing Kunkel et al. 2013a). The frequency, intensity, and duration of heat waves is projected to increase under both emissions scenarios, with the greatest increase seen under the higher (A2) emissions scenario (GCRP 2014). By the end of the century and in the absence of global GHG mitigation, parts of the Northeast may experience an increase in extreme temperatures ranging from 7 to 10°F relative to today's conditions (EPA 2015g).[70] Conversely, the frequency, intensity, and duration of cold air outbreaks is expected to decrease throughout the century; although a loss of Arctic sea ice could dilute this effect by affecting the jet stream and mid-latitude weather patterns (GCRP 2014 citing Francis and Vavrus 2012 and Liu et al. 2012). The southern portion of the Northeastern region, including Maryland, Delaware, and southwestern West Virginia and New Jersey is projected to experience an additional 60 days per year above 90°F under the higher (A2) emissions scenario, relative to the 1971 to 2000 mean (GCRP 2014).

Precipitation has increased by approximately 5 inches (more than 10 percent) at a rate of 0.4 inches per decade (GCRP 2014 citing Kunkel et al. 2013a), from 1895 to 2011. Fall precipitation also exhibited a statistically significant increase of 0.24 inches per decade over the same time period, while spring, summer, and winter increases are not statistically significant (Kunkel et al. 2013a). Future changes in precipitation exhibit greater uncertainty than temperature projections (GCRP 2014 citing Kunkel et al. 2013a). Winter and spring precipitation is, however, projected to increase in some parts of the Northeast such as the northern part of the region (GCRP 2014). Averaged across the Northeastern region, models project between a 5 and 20 percent increase (at the 25th and 75th percentiles, respectively) in winter precipitation under the higher (A2) emissions scenario, relative to a 1971 to 1999 mean. For the same time period and emissions scenarios, summer and fall precipitation are projected to increase by only a small amount when compared to natural variations (GCRP 2014 citing Kunkel et al.

[70] Extreme temperature was based on an extreme heat index defined as the 99% or the hottest 4 days of the year.

2013a and Karl et al. 2009). In addition to an increase in heavy rainfall events, winter precipitation is expected to fall increasingly as rain, rather than snow (EPA 2009).

Extreme precipitation in the Northeast, defined as the amount of precipitation falling in the heaviest 1 percent of all daily events, has increased by more than 70 percent between 1958 and 2010 (GCRP 2014 citing Groisman et al. 2012). The frequency of heavy downpours is expected to continue its upward trend throughout the century (EPA 2015g). At the same time, the risk of droughts in the summer and fall is expected to increase due to higher evaporation rates and earlier winter and spring snowmelt (GCRP 2014 citing NPCC 2010). Despite the increased risk of seasonal drought, the Northeast is estimated (under IGSM-CAM projections) to experience a reduction in the areas burned by wildfire (EPA 2015g). Coastal flooding in the Northeast has increased due to sea-level rise of nearly 1 foot since 1900 (GCRP 2014). In Philadelphia, for example, sea level rose 1.2 feet from 1901 to 2012 (GCRP 2014 citing NOAA 2013b). Sea-level rise in the Northeast has outpaced the global average sea-level rise of 8 inches over the same time period, primarily because of land subsidence (GCRP 2014 citing Church et al. 2010). Recent research suggests that a weakening of the Gulf Stream may also play a role (GCRP 2014 citing Sallenger et al. 2012).

Global sea levels are projected to rise between 1 and 4 feet by 2100 relative to 1992 (GCRP 2014 citing Parris et al. 2012). Just as sea-level rise in the Northeast during the last century exceeded global sea-level rise, so too it is expected that future sea-level rise in the Northeast will outpace global sea-level rise. This phenomenon would be exacerbated if the Gulf Stream were to weaken (GRCP 2014 citing Sallenger et al. 2012 and Yin et al. 2009). Today's storm events occurring at a sea-level rise of 2 feet would more than triple the frequency of dangerous coastal flooding across much of the Northeast (GCRP 2014 citing Horton et al. 2011). In the New York City Battery area, for example, there is a flood event of a certain magnitude that, from a baseline period 2000 to 2004, had a 1 percent chance of occurring or being exceeded each year. By 2050, the probability of a flood event of that same magnitude occurring or being exceeded each year increases to between 1.4 and 5 percent (this range represents the 10^{th} and 90^{th} percentile of 35 different climate model runs, each of which used the RCP4.5 [lower] and RCP8.5 [higher] emissions scenarios) (New York City Panel on Climate Change 2013). Such extreme storm events cause excess mortality and morbidity along the East Coast of the United States (IPCC 2014c).

Table 5.5.3-1 summarizes the projected trends for climate variables in the Northeast and the associated resources the trends will affect.

Table 5.5.3-1. Observed and Projected Trends in Environmental Variables for the Northeast

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Increase in temperature of 2 ˚F (0.16 ˚F per decade) between 1895 and 2011; more pronounced warming during the winter and spring; increase in freeze-free season.	Increase in annual average temperatures with shorter, warmer winters and longer growing seasons; increase in number of days above 95˚F throughout the region.	▪ Food, fiber, and forest products ▪ Urban areas ▪ Rural areas ▪ Human health
Precipitation	Increase in precipitation of 5 inches (0.4 inches per decade), or 10% between 1895 and 2011; 70% increase in heavy precipitation events.	Increase in annual precipitation; decrease in summer precipitation and an increase in winter precipitation; increase in frequency of seasonal droughts; decrease in length of snow season; increase in number of wet days.	▪ Freshwater resources ▪ Urban areas ▪ Rural areas
Sea level	Approximately 1 foot increase (1.2 inches per decade) in sea levels since 1900.	Increase in sea levels greater than global average, which is projected to rise between 1 and 4 feet by 2100.	▪ Ocean systems, coastal, and low-lying areas ▪ Urban areas ▪ Rural areas ▪ Human health ▪ Freshwater resources

Notes:

Sources: GCRP 2014, Kunkel et al. 2013a.

5.5.3.1.2 Freshwater Resources

Changes to freshwater resources are already occurring in the Northeast. For example, earlier snowmelt has caused the flow of rivers and streams in New England to peak earlier in the season, which affects both aquatic organisms and water supply management (Kunkel et al. 2013a). Snow depth has additionally experienced a decline in recent decades. For example, 18 of 23 snow areas surveyed in Maine decreased in depth, with mountainous sites along the Maine–New Hampshire border showing a decrease of 16 percent from 1926 to 2004 (Kunkel et al. 2013a citing Hodgkins and Dudley 2006).

Sea-level rise is projected to increase saltwater infiltration into freshwater distribution systems (GCRP 2014 citing NPCC 2010). In New York City, coastal wetlands will be lost as sea-level rises, as coastal development prevents wetlands from naturally moving inland (IPCC 2014b citing Gaffin et al. 2012). As much as 21 percent of the U.S. mid-Atlantic coastal wetlands are potentially at risk of inundation between 2000 and 2100 (EPA 2009). Coastal wetlands already experiencing submergence are *virtually certain* to continue to shrink due to accelerated sea-level rise, among other climate- and non-climate-related factors (EPA 2009).

Increased eutrophication due to warming water temperatures will incur costs related to the upgrading of municipal drinking water treatment facilities and purchase of bottled water. Additionally, sea-level rise poses an additional risk to water treatment facilities. EPA has identified more than $200 billion in wastewater management infrastructure in need of upgrading to protect from nutrient pollution (Baron et al. 2013 citing EPA 2011).

5.5.3.1.3 Terrestrial and Freshwater Ecosystems

Ecosystems in the Northeast region have already experienced a number of negative impacts from climate change. For example, species have been observed in the Green Mountains of Vermont moving upslope (GCRP 2014 citing Beckage et al. 2008), certain flowers are blooming earlier (GCRP 2014 citing Primack et al. 2004), and migratory birds are arriving sooner (GCRP 2014 citing Butler 2013). Species that find difficulty in adjusting to changes in migration patterns or food availability are increasingly vulnerable to the impacts of climate change (GCRP 2014). For example, while some bird and insect species have been able to expand their range to the north, hemlock trees have been unable to resist invasive insects and have experienced a reduction in population.

Rising air and ocean temperatures can also negatively affect Northeastern ecosystems. Warmer winter temperatures, coupled with less snowfall, have benefitted deer, which degrade forest vegetation (GCRP 2014 citing Stromayer and Warren 1997). Increasing ocean temperatures are projected to shift the range of economically important marine species northward, such as cod and lobster. This could cause significant declines in fisheries south of Cape Cod (GCRP 2014 citing Fogarty et al. 2008 and Frumhoff et al. 2007). While fish species adapted to cold water could decline and those adapted to warm water could increase as ocean temperatures increase, there remains considerable uncertainty over the ability of those species to adapt to shifts in climate zones. Similarly, while hardwood trees in the Northeast region are projected to benefit from increased concentrations of CO_2, this productivity increase could be offset by summer drought and other impacts of climate change (GCRP 2014 citing Mohan et al. 2009). Climate change is also projected to increase populations of insect pests, pathogens, and invasive plants that reduce biodiversity, function, and resilience of Northeastern ecosystems.

5.5.3.1.4 Ocean Systems, Coastal, and Low-Lying Areas

The Northeast includes densely populated coastal areas that are extremely vulnerable to projected increases in the extent and frequency of storm surge, coastal flooding, sea-level rise, property damage, and loss of wetlands (GCRP 2014). The region has already felt the impact of coastal flooding and property damage. Hurricane Irene caused New York City to close its mass transit system and authorities ordered the mandatory evacuation of 2.3 million coastal residents (GCRP 2014); New York City is one of two U.S. cities projected to be among the top 20 cities worldwide in terms of population exposed to coastal flooding (Hanson et al. 2011).

As much as 21 percent of the U.S. mid-Atlantic coastal wetlands are potentially at risk of inundation between 2000 and 2100, and coastal wetlands already experiencing submergence are "*virtually certain*" to continue to shrink due to accelerated sea-level rise, among other climate- and non-climate-related factors (EPA 2009). In addition, melting of the Greenland ice sheet could have an effect on ocean circulation and sea-level rise dynamics, which might exacerbate sea-level rise experienced on the northeastern coast of the United States and in Canada (Hu et al. 2009).

Climate change is projected to further affect urban and rural areas throughout the Northeast. A sea-level rise of 2 feet, which is toward the lower end of global projections (between 1 and 4 feet by 2100 relative to 1992 levels), would flood or render unusable 212 miles of roadway, 77 miles of rail, 3,647 acres of airport facilities, and 539 acres of runways absent any adaptation investment (GCRP 2014 citing DOT 2008). In Maryland, 2 feet of sea-level rise would flood 32 percent of port facilities, which generate over 50,000 jobs and $3.6 billion in personal income (based on 2006 values) (GCRP 2014 citing Maryland Port Administration 2008). States in the southern portion of the Northeast, such as Delaware and Maryland, are projected to face greater impacts from sea-level rise than northern states due to a higher rate of sea-level rise and flat coastlines (GCRP 2014). However, the northern states are not exempt from impacts; low-lying areas in Boston could face up to $94 billion in building damage and emergency response costs from 2000 to 2100 depending on sea-level rise and adaptation actions (GCRP 2014 citing Kirshen et al. 2008a).

More generally, sea-level rise and an increase in frequency and intensity of coastal flooding would affect communications, energy, transportation, and water and waste infrastructure in the coming century. Impacts include damage to communications equipment in low-lying areas; inundation of coastal power plants; flooding of streets, subways, bridges, and tunnels; and release of pollution and contaminant runoff from sewer systems.

5.5.3.1.5 Food, Fiber, and Forest Products

Farmers in the Northeast region are already witnessing the impacts of climate change. Intense precipitation events, which have increased by more than 70 percent between 1958 and 2010, have damaged crops. Wet spring seasons have delayed grain and vegetable planting in regions such as New York, which delays harvest dates and reduces yields (GCRP 2014). Counterintuitively, frost damage has actually increased over the past decade because crops that soften due to winter warm spells are increasingly susceptible to subsequent freeze damage (GCRP 2014).

Weed and pest prevalence, which could increase as growing seasons lengthen and winters warm, pose further risks to crops. The Northeast region has already observed earlier arrivals and increased populations of some pests, such as corn earworm (GCRP 2014 citing Wolfe et al. 2008). Additionally, certain aggressive weeds such as kudzu benefit disproportionally from increased atmospheric CO_2 concentrations. Weed-killers could lose efficacy on weeds grown under higher atmospheric CO_2 concentrations (GCRP 2014 citing Ziska et al. 1999). All of the competition studies that compare the photosynthetic pathway for both weeds and crops have concluded that weed growth will benefit more than crop growth (GCRP 2014 citing Ziska and Runion 2007). Finally, as summer temperatures rise, growing seasons lengthen, and heat stress increases, farmers could face water shortages to meet demand (GCRP 2014 citing Hayhoe et al. 2007 and Wolfe et al. 2011).

5.5.3.1.6 Urban Areas and Rural Areas

Sea-level rise, increases in frequency and intensity of coastal flooding, and extreme precipitation events pose a risk to urban and rural areas alike. During the summer of 2011, Hurricane Irene hit Vermont and brought with it significant inland flooding resulting in more than 500 miles of damaged roads and 200 damaged bridges. Rebuilding costs amounted to between $175 and $250 million (GCRP 2014). Hurricane Sandy resulted in roughly 150 deaths, damaged or destroyed 650,000 homes, and incurred between $60 and $80 billion in damages, second only to Hurricane Katrina as the most costly Atlantic Hurricane (GCRP 2014 citing Blake et al. 2013 and NOAA 2013). In New Jersey alone, repairing damaged power and gas lines is expected to cost roughly $1 billion, while fixing waste, water, and sewer systems is expected to cost $3 billion (GRCP 2014 citing Blake et al. 2013 and NOAA 2013b). Douglas et al. (2013) determined that damage in Boston from Hurricane Sandy could have been much worse—were Hurricane Sandy to have hit Boston 5.5 hours later, at high tide, up to 6 percent of Boston could have been flooded. Furthermore, a Sandy-type storm occurring with 2.5 feet of sea-level rise (within the projected 1- to 4-foot range by 2100), could cause over 30 percent of Boston to flood (Douglas et al. 2013).

Climate change could have other impacts on urban and rural areas. For example, urban and rural populations could increasingly demand air conditioning in the summer (*see* Section 5.5.3.1.7 for further discussion of the impact of heat events on human health), when higher electricity demand could shrink the capacity reserve margins in the power system. Recreational sites such as parks and playgrounds are often located in low-elevation areas, and will be increasingly susceptible to storm surge flooding (*see* Section 5.5.2.3 for further discussion of the impact of storm surge on low-lying areas) (IPCC 2014b citing Rosenzweig and Solecki 2010).

5.5.3.1.7 Human Health

The projected increase in extreme heat events in the Northeast region could have significant implications for human health. Extreme heat events can lead to hospitalization and even premature death (GCRP 2014). One study projects that temperature increases would result in a 50 to 91 percent increase in heat-related deaths in Manhattan by the 2080s, relative to a 1980s baseline (GRCP 2014 citing Li et al. 2013). Moreover, in the rural areas of the Northeast region, air conditioning is not as prevalent as in urban areas. Areas of Northern New England, where heat waves have historically been rare, are projected to experience an increase in the number of hot days (>90 ^{o}F temperatures) from less than 5 to more than 15 per year by the 2050s under the higher (A2) warming scenario. Accordingly, these communities are especially vulnerable to high temperatures (GCRP 2014 citing Kunkel et al. 2013a). In the absence of GHG mitigation, major Northeast cities are projected to experience an additional 2,400 extreme temperature mortalities in total compared to a scenario that substantially mitigates GHG emissions (EPA 2015g).

Increased temperatures can worsen air quality. Poor air quality causes respiratory ailments and can lead to premature mortality. These impacts, coupled with heat stress, will disproportionately affect vulnerable populations such as children, the elderly, low-income families, minorities, women,[71] less-educated citizens, rural residents, and people with pre-existing health conditions such as asthma (GCRP 2014). Increased ground-level ozone from warming is projected to result in a 7.3 percent increase in asthma-related emergency department visits in New York metropolitan area by the 2020s under the higher (A2) warming scenario, relative to a 1990 baseline of 650 visits (GCRP 2014 citing Sheffield et al. 2011b).

Climate change could also increase both the frequency and potency of plant allergens. Changes in temperature and precipitation patterns could change the amount and timing of airborne allergens like pollen grains and fungal spores. Latitudes above 44^{o}N have already experienced an increase in number of days in the ragweed pollen season of between 13 and 27 days per year since 1995 (GCRP 2014 citing Ziska et al. 2011). These changes could worsen allergy symptoms and even increase the prevalence of allergic diseases in the Northeast region (Frumhoff et al. 2007 citing Ziska et al. 2008). As indicated in experiments, increased concentrations of CO_2 can increase the allergenic potential of poison ivy (Frumhoff et al. 2007 citing Ziska and George 2004 and Mohan et al. 2006) and pollen-producers such as ragweed and pine trees (Frumhoff et al. 2007 citing Wayne et al. 2002 and Ziska and Caulfield 2000).

The prevalence of vector-borne and waterborne illnesses, such as West Nile virus, could also increase under warming scenarios. Suitable habitat for the Asian Tiger Mosquito, a carrier of West Nile virus, is projected to increase from the current 5 percent of total land area in the northeastern United States to 16 percent in the next 20 years, and between 43 percent (under the lower [B2] emissions scenario) and 49 percent (under the higher [A2] emissions scenario) by 2100 (GCRP 2014 citing Rochlin et al. 2013). This would expose an additional 30 million northeastern residents to West Nile virus. Waterborne disease from untreated wastewater is sometimes released into local water bodies

[71] According to Cutter (2003), in terms of health impacts, "women can have a more difficult time during recovery than men, often due to sector-specific employment, lower wages, and family care responsibilities." (pg. 246)

during extreme precipitation events. This can increase the risk of stomach illness—in Connecticut, for example, one study concluded that the risk of contracting a stomach illness while swimming increased after intense rainfall events (more than 1 inch of precipitation in a 24-hour period) (GCRP 2014 citing Kuntz and Murray 2009), while in Milwaukee, another study found a correlation between diarrheal illness in children and sewage discharge from heavy rain events (GCRP 2014 citing Redman et al. 2007).

Not all human health impacts are projected to be negative. Along with an increase in heat-related deaths, a reduction in cold-related deaths is also projected (GCRP 2009). However, in temperate regions, including the Northeast, the reduction in cold-related deaths is not likely to entirely offset the increase in heat- related deaths (Frumhoff et al. 2007 citing Campbell-Lendrum and Woodruff 2006 and McMichael et al. 2006).

5.5.3.2 Southeast and the Caribbean

This section describes climate change impacts in the Southeast region of the United States—Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and Puerto Rico—and the Caribbean. The Southeast region has 29,000 miles of coastline (GCRP 2014 citing NOAA 2010), including some of the areas in the continental United States that are most vulnerable to sea-level rise. Additionally, the region faces impacts from hurricanes and tropical storms, storm surge, erosion, saltwater intrusion, and heavy rain events. Overall, it has endured more billion-dollar weather disasters than any other U.S. region (GCRP 2014). Increases in average temperatures and changes in precipitation from climate change will affect human health; freshwater resources; food, fiber, and forest products; and terrestrial and freshwater ecosystems.

5.5.3.2.1 Observed and Projected Changes in Exposure

Over the past century, global sea level has risen about 8 inches (GCRP 2014). Land subsidence has resulted in slightly higher sea-level rise in the northern Gulf of Mexico and along the East Coast (Ingram et al. 2013 citing Mitchum 2011). Since the early 20th century, relative sea levels have risen by 0.08 to 0.12 inches (2.03 to 3.05 millimeters) per year along the Atlantic and Gulf Coasts (National Science and Technology Council 2008, EPA 2009). By reconstructing sea levels over the past 2,100 years, Kemp et al. (2011) found that sea level was relatively stable along the North Carolina coast from 100 BC until 950 AD, after which levels increased by 0.02 inches (0.6 millimeters) per year for 400 years, followed by a stable period until the 19th century. Sea level is projected to continue to rise with local projections varying based on rates of subsidence/uplift and changes in offshore currents (GCRP 2014 citing Parris et al. 2012 and Sallenger et al. 2012).

This is a region that experiences large spatial variability in annual temperatures from the warm Florida Keys to the cooler Appalachian mountain range. Although oscillating warm and cool periods have resulted in the Southeast experiencing no long-term average annual temperature trend since 1900 (i.e., over the entire record), there has been an increase by an average of 2°F since 1970 relative to 1901-1960, and the decade 2001 to 2010 was the warmest on record (GCRP 2014). This warming has been more notable during the summer months, particularly along the region's coastline (Kunkel et al. 2013b). While the number of hot days above 95°F per year slightly decreased during the 20th century, there has been an upward trend since the 1970s (Kunkel et al. 2013b). In addition, warm nights above 75°F have increased since the 1970s (GCRP 2014). Intense cold wave events have experienced no trend over the past century (Kunkel et al. 2013b). The number of days with temperatures remaining below freezing has generally fallen across the Southeast since the 1931 to 1970 period, and this decrease is more pronounced in the northern part of the Southeast (Kunkel et al. 2013b). Kaushal et al. (2010) documented rising water temperatures in streams and rivers throughout the United States, including the

Potomac River. The Caribbean has experienced increasing hot days (with temperatures above 95°F) and nights (temperatures above 75°F) since the 1950s (GCRP 2014 citing PRCCC 2013).

Over the coming century, interior states are projected to warm by 1 to 2°F greater than coastal regions, with the regional average temperature projected to increase by 4 to 8°F, and temperatures in Puerto Rico are projected to rise between 2 to 5°F by the year 2100 (the range provided spans the 25th to 75th percentile range for higher (A2) and lower (B1) emissions scenarios) relative to 1901 to 1960 (GCRP 2014). By the 2041 to 2070 period, hot days (with maximum temperatures above 95°F) are projected to significantly increase by 27 days, under the higher (A2) emissions scenario, with southern Florida experiencing nearly 50 additional hot days per year relative to the 1971–2000 (Kunkel et al. 2013b, GCRP 2014 citing Kunkel et al. 2013b). Days below 32°F are projected to decrease in most of the region by between 5 and 20 days for the 2041 to 2070 period under the higher (A2) emissions scenario, with Kentucky, Tennessee, and Virginia experiencing nearly 25 fewer cold days per year relative to the 1980 to 2000 average (Kunkel et al. 2013b).

Since 1900, there has not been a statistically significant trend in annual precipitation for the Southeast region as a whole, except along portions of the Gulf Coast which exhibited increases in annual precipitation (Kunkel et al. 2013b). Despite the lack of an annual trend throughout the Southeast region, fall precipitation has increased and summer precipitation has decreased since 1900 (Kunkel et al. 2013b). While many climate models project small precipitation changes relative to natural variations in the coming years, the southwest part of this region is expected to become drier while the northeast is expected to become wetter (Kunkel et al. 2013b). In the Caribbean, the majority of models suggest decreases in precipitation (GCRP 2014 citing PRCCC 2013).

Across the Southeast, daily and 5-day rainfall intensities have increased (GCRP 2014 citing Ingram et al. 2013). The region has also experienced both increasingly arid and extremely wet summers (GCRP 2014 citing Kunkel et al. 2013b). Under a moderately low (RCP4.5) emissions scenario, interannual variability of both drought and wet conditions is projected to increase over the course of the 21st century (Wuebbles et al. 2014). Trends of increasing extreme precipitation witnessed both during the 20th century and the past decade are expected to continue throughout the coming century (GCRP 2014, EPA 2015g).

While there is some disagreement amongst scientists regarding the increasing or decreasing trend in the number of Atlantic hurricane and major hurricane landfalls over the past century (Kunkel et al. 2013b citing Blake et al. 2011 and Mann and Emanuel 2006; Landsea et al. 2010), some studies suggest that both climate change and natural variability has contributed to an increase in the number of Category 4 and 5 hurricanes in the Atlantic basin since the 1980s compared to the historical record (mid-1880s) (GCRP 2014). While the number of tropical storms is projected to decrease in number globally, their intensity is projected to increase, along with the prevalence of Category 4 and 5 storms (GCRP 2014 citing Knutson et al. 2010). Grinsted et al. (2013) estimate that a 1.8°F (1°C) increase in global temperature could result in a twofold to sevenfold increase in the frequency of Hurricane Katrina-magnitude events by 2100 under the lower (RCP4.5) emissions scenario.

In the Atlantic Ocean, sea surface temperatures are projected to increase, which could play a role in increasing the intensity of hurricanes. Rising sea levels, coupled with a likely increase in hurricane intensity, will contribute to greater storm-surge height, erosion, and flooding (GCRP 2014). Model results for a study of climate change impacts (i.e., sea-level rise) along the Gulf Coast conservatively estimated a range of 6.7- to 7.3-meters (22- to 24-foot) potential maximum surge for Category 3 hurricanes and 9 meters (30 feet) for Category 5 hurricanes. Observed storm surges during hurricanes Camille and Katrina reached 7.6 meters (25 feet) and 8.5 meters (28 feet), respectively (CCSP 2008a). Table 5.5.3-2 summarizes the projected trends for climate variables in the Southeast and the associated resources the trends will affect.

Table 5.5.3-2. Observed and Projected Trends in Environmental Variables for the Southeast

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	No 20th century temperature trend; recent warming observed since 1970 with average annual temperatures increasing 2°F along with an increase in hot days, warm nights, and a decline in cold events.	Average temperatures projected to increase by 4 to 8°F by 2100; temperatures in Puerto Rico expected to rise 2 to 5°F by 2100; greater warming for interior states relative to coastal states; increasing hot days; decreasing cold nights.	▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Freshwater resources ▪ Human health ▪ Human security
Precipitation	No statistically significant annual precipitation trend since 1900; statistically significant increase in fall precipitation and decrease in summer precipitation; increase in daily and 5-day rainfall intensities.	More frequent and intense heavy downpours; drier conditions in the south; wetter conditions in the north; more variable drought and wet conditions.	▪ Freshwater resources ▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal and low-lying areas ▪ Food, fiber, and forest products
Sea level	Sea-level rise of 8 inches since 1900 (0.08 to 0.12 inches per year); similar to global trend, augmented by subsidence in different locations.	Sea-level rise of 1 to 4 feet above 1992 levels by 2100 with higher rise projected for some locations along the Southeast coastline (largely due to subsidence).	▪ Freshwater resources ▪ Ocean systems, coastal and low-lying areas ▪ Terrestrial and freshwater ecosystems ▪ Human security

Notes:
Sources: GCRP 2014, Kunkel et al. 2013b.

5.5.3.2.2 Freshwater Resources

Despite uncertainties in projections of precipitation changes in the Southeast, evaporative losses are expected to increase with rising temperatures, leading to reduced water availability (GCRP 2014 citing PRCCC 2013, Ingram et al. 2013). Annual water availability in the Southeast is projected to decrease from roughly 17 inches in 2010 to about 14 inches by 2060 based on moderate (A1B) and low (B2) emissions scenarios (GCRP 2014 citing Sun et al. 2013). Projections vary within the region, but the western states in the Southeast (Louisiana, Arkansas, Alabama, northern Mississippi, Tennessee, and Kentucky) exhibit a statistically significant change in water availability, a decrease of between 5 and 6.4 percent by 2060 (GCRP 2014 citing Sun et al. 2013). Similarly, the Caribbean is expected to face severe water stress across all emissions scenarios (GCRP 2014 citing UNEP 2008).

Sea-level rise is contributing to a greater risk of saltwater intrusion into freshwater resources, such as aquaculture operations and aquifers (GCRP 2014 citing Twilley et al. 2001, SFWMD 2009, and Obeysekera et al. 2011). Saltwater migration into the surface waters of the southern Everglades would contaminate the Biscayne Aquifer at its headwaters, threatening Miami-Dade County's wellfields, which supply 2.5 million residents with potable water (Bloetscher et al. 2011). The city of Hallandale Beach, Florida, has already abandoned six of eight drinking water wells (GCRP 2014 citing Berry et al. 2011). Freshwater resources will also face competition from the agriculture (from rising food production to meet increased demand), energy (from increased air conditioning needs), and urban (to supply residents with drinking water) sectors (GCRP citing Ingram et al. 2013). Coastal communities might have to establish new freshwater wells farther inland in order to reduce their vulnerability to saltwater intrusion (GCRP 2014).

5.5.3.2.3 Terrestrial and Freshwater Ecosystems

Projected climate change will affect natural ecosystems and wildlife in the Southeast. Some tidal freshwater forests are retreating, while mangrove forests traditionally adapted to coastal ecosystems are moving landward (GCRP 2014). Since 1930, Louisiana has lost 1,800 square miles of coastal wetlands as a result of both natural and anthropogenic factors (GCRP 2014 citing State of Louisiana 2012 and Couvillion et al. 2011). The low-lying coast of Louisiana, which currently loses 6,200 hectares of wetlands per year, could be entirely underwater by 2100 with up to 4 feet of sea-level rise (Ingram et al. 2013 citing ASP 2011). Saltwater intrusion threatens estuarine and mangrove ecosystems, and has already been linked to the decline of bald cypress forests in Louisiana, cabbage palm forests in Florida, and the inland encroachment of salt-tolerant mangroves in Florida (EPA 2009, NRC 2008). A recent study assessing species vulnerabilities in the Gulf Coast found that of the eleven species considered, the Kemp's ridley sea turtle is the most vulnerable animal species to climate change due to nesting habitat loss. However, avian species overall are more vulnerable to climate change than aquatic species (also due to nesting habitat loss from sea-level rise, erosion, and potential impacts of storm surge) (Watson et al. 2015).

Increases in seasonal and annual temperatures, as well as sea-level rise, will also affect natural systems. For example:

- Reduction of wetlands from sea-level rise and other factors increases the likelihood of a loss of fishery habitat. Furthermore, warming sea temperatures may increase invasive species, changes in species growth rates, shifts in migratory patterns or dates, and alterations to spawning seasons (GCRP 2014 citing PRCCC 2013 and Osgood 2008).
- Changes in salinity and sea-level rise can outpace the ability of local vegetation to adapt. Similarly, wildfires, hurricanes, and other extreme weather events could produce similar outcomes, potentially pushing local ecosystems past a destabilizing point (GCRP 2014 citing IPCC 2007b and Burkett 2008; Burkett 2005).
- Although it is uncertain whether the Southeast will be wetter or drier under future climate change, closed-canopy forests could be threatened by drought stress, even under somewhat wetter conditions, due to higher average temperatures and increases in fire disturbance (CCSP 2008c).

5.5.3.2.4 Ocean Systems, Coastal, and Low-Lying Areas

Sea-level rise, increased hurricane intensity, storm surge, erosion, and saltwater intrusion are among the most serious climate change impacts facing the Southeast region. Miami is in the top 20 cities worldwide in terms of population exposed to future coastal flooding, and Miami, New Orleans, and Virginia Beach are all among the top 20 cities with the highest value of assets exposed to future coastal flooding impacts (Hanson et al. 2011, Weiss et al. 2011). In Miami, sea level rose 0.09 plus or minus 0.009 inches (2.39 plus or minus 0.22 millimeters) per year from 1913 to 1999, and barrier islands in the Tampa Bay region are already affected by significant beach erosion due to sea-level rise (Bloetscher et al. 2011). One analysis suggests that annual damage to assets on the Alabama, Mississippi, Louisiana, and Texas coastlines from hurricanes, subsidence, and sea-level rise could increase from the current $14 billion to between $18 and $23 billion, depending on the change in hurricane wind speed and sea-level rise (GCRP citing AWF, AEC, and Entergy 2010). The authors attribute roughly 50 percent of the increase in damages to climate change.

Transportation, utility, and energy sectors are projected to be affected by an increasing number of heavy rain and storm surge events. For example, Louisiana State Highway 1 is subsiding, putting the economically important oil and gas hub at risk of severe flooding (GCRP 2014 citing State of Louisiana 2012). The Department of Homeland security calculated that a 90-day severe flooding event at Louisiana State Highway 1 would cost $7.8 billion (GCRP 2014 citing DHS 2011). Further, 1 meter (3.3 feet) of sea-level rise combined with 7 meters (23 feet) of storm surge could inundate more than half of all highways, arterials, and rail lines along the U.S. Gulf Coast (GCRP 2014 citing CCSP 2008a). Sea-level rise of 4 feet would permanently inundate 27 percent of roads, 9 percent of railways, and 72 percent of ports in the Gulf Coast (CCSP 2008a).

Water and energy utilities are expected to face pressure from saltwater intrusion into freshwater systems. Periods of drought can further reduce the availability of freshwater for municipal and agricultural consumption (GCRP 2014). In fact, the droughts experienced over recent decades have led to significant socioeconomic and ecological impacts (EPA 2015g). Inland flooding could impair the ability of stormwater drainage systems to empty into the ocean (GCRP 2014 citing Bloetscher et al. 2011). Offshore oil and gas production infrastructure is expected to become increasingly vulnerable to storm surge as barrier islands that once protected them erode into the sea (GCRP 2014 citing Burkett 2011).

Many of the low-lying coastal areas exposed to sea-level rise, hurricanes, and storm surge are also at high risk of erosion. Significant erosion is already occurring along the east coast and in the coastal wetlands of Louisiana from a combination of factors, including climate change induced sea-level rise and land subsidence (National Science and Technology Council 2008 citing Nicholls et al. 2007). Horizontal erosion rates on Mississippi shorelines have been between 8.5 and 10.2 feet per year since the 1970s[72]; in contrast, 90 percent of the Louisiana shoreline has eroded at 39 feet per year (EPA 2009 citing IPCC 2007). The coastline of Puerto Rico is eroding at a rate of 3.3 feet per year due to current sea-level rise (GCRP 2014 citing PRCCC 2013). In Louisiana, barrier-island erosion is resulting in increased wave height along the coast (National Science and Technology Council 2008 citing Nicholls et al. 2007).

Finally, climate change is expected to also affect coral reefs, which are already facing stress from overfishing, pollution from land-based runoff of nutrients and sediments, coastal developments, and disease. Reefs off the Florida Keys and in tropical waters in the United States face a dual threat from both warmer sea water and ocean acidification, which are expected to challenge their survival (GCRP 2014, EPA 2015g). By 2025, coral reefs in the Caribbean may be severely affected by high-temperature bleaching events (EPA 2015g).

5.5.3.2.5 Food, Fiber, and Forest Products

Warmer temperatures, declines in soil moisture, and water scarcity will have impacts on agriculture in the Southeast region. Decreased freshwater availability, land loss, and saltwater intrusion could negatively affect agricultural production (GCRP 2014). Miami-Dade County and southern Louisiana, which have shallow groundwater tables, would lose 37,500 acres of cropland with a 27-inch rise in sea levels (within the 1- to 4-foot range projected by 2100) (GCRP 2014 citing Stanton and Ackerman 2007).

Dairy and livestock production are sensitive to increasing summer temperatures. With a 9°F temperature increase (slightly higher than the 4 to 8°F projected by end of century under the 75th percentile range across the lower [B2] and higher [A2] emissions scenarios), the Southeast region may experience a 10

[72] This statistic was developed for the Mississippi and Texas shoreline.

percent decline in livestock yields largely driven by the warmer summers (GCRP 2014 citing Adams et al. 1999). Crop productivity would similarly be negatively affected by summer heat stress, as well as drought and an increase in non-native plant species (GCRP 2014 citing Hellmann et al. 2008). While increasing CO_2 concentrations would increase the productivity of corn and wheat, increasing temperatures are projected to outweigh this effect due to summer heat stress (GCRP 2014 citing Hatfield et al. 2008). In Georgia, rising temperatures could lead to declines in corn and wheat yields of 15 and 20 percent, respectively, through 2020 (GCRP 2014 citing Alexandrov and Hoogenboom 2000). Fruit crops that require chilling periods could also be displaced as the southeastern climate warms (GCRP 2014 citing Hatfield et al. 2008). Assuming no mitigation of GHG emissions, irrigated soybean yields are projected to decrease by 23 percent relative to current yields by the end of the century (EPA 2015g).

Forest-damaging wildfires are projected to increase as warming continues. Wildfires in the Southeast region, which experiences the greatest number of wildfires in the United States,[73] are expected to grow in intensity, number, and size under increasing temperatures and drought conditions (though up to a specific threshold, as increased fire frequency results in reduced fire intensity) (GCRP 2014 citing Gramley 2005 and Butry et al. 2001). Climate change is projected to further disturb forests by modifying insect and pathogen occurrences. Rising temperatures have affected certain populations of insects, such as the Hemlock woolly adelgid in the Southern Appalachians which has increased in recent years due to increasing temperatures; on the other hand, Southern Pine Beetle outbreaks have decreased (GCRP 2014 citing Friedenberg et al. 2007).

5.5.3.2.6 Human Health

Higher temperatures could affect human health by contributing to illness and even death in periods of extreme heat. Days over 95°F have increased in Atlanta, Miami, New Orleans, and Tampa, leading to an above-average number of deaths. Extreme heat events are projected to increase the formation of ground-level ozone in the 19 largest urban areas in the Southeast region relative to 2001 under the moderate (A1B) emissions scenario, which would lead to higher incidence of respiratory illness, asthma-related emergency room visits, and lost school days (GCRP 2014 citing Portier et al. 2010, Chang et al. 2010, and Tagaris et al. 2009). Forest fires also negatively affect human health by both causing direct injuries and lowering air quality (GCRP 2014 citing Butry et al. 2001, Albrecht et al. 2007, Ebi et al. 2008, and Delfino et al. 2009).

While it is uncertain how climate change will affect the spread of disease vectors like mosquitoes carrying malaria, yellow and dengue fever, increasing temperatures could result in expanded mosquito habitat (GCRP 2014 citing Filler et al. 2006, Mali et al. 2012, and Trout et al. 2010). Increased incidents of algal blooms due to warmer sea surface temperatures could result in higher rates of ciguatera fish poisoning (GCRP 2014 citing Tester et al. 2010 and Hales et al. 1999). Furthermore, warming sea surface temperatures could cause these algal blooms to move northward, as would bacteria present in shellfish, such as Vibrio (GCRP 2014 citing Litaker et al. 2010). Vibrio-related infections are now beginning earlier in the year and ending later in the year, compared to historical observations (GCRP 2014 citing Litaker et al. 2010).

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[73] The data defines a larger Southeast area, including Texas and Oklahoma.

5.5.3.2.7 Human Security

Storm surge and extreme weather threatens human wellbeing and livelihoods, especially in poor and disadvantaged communities located in low-lying areas. For example, as floodplains increase in size due to greater incidence of storm surge, insurance costs are expected to escalate, disproportionally affecting low-income communities (GCRP 2014 citing Leurig and Dlugolecki 2013). Insurance coverage could then become unaffordable or even unavailable, forcing residents to migrate to less vulnerable areas that could be unprepared to accept a population influx. For example, after Hurricane Katrina, 200,000 Gulf Coast residents moved to Houston, 42 percent of this population have indicated their desire to remain in Houston (GCRP 2014 citing Coker et al. 2006). In the Gulf Coast region, virtually all of the most socially vulnerable residents live in areas unlikely to see adaptation investment from storm surge due to low property values (GCRP 2014 citing Martinich et al. 2013).

Increased summer temperatures are expected to stress existing power plant capacity in the Southeast region, which has a greater capacity than any other U.S. region (GCRP 2014 citing EIA 2011). Increases in power demand, and inevitably energy prices, will disproportionately burden low-income households, the elderly, and native tribes (GCRP 2014 citing Ingram et al. 2013 and Coastal Louisiana Tribal Communities 2012).

5.5.3.3 Midwest

The Midwest region includes Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. Across the Midwest, where more than 61 million people populate the vast agricultural lands, northern forests, and major urban centers, which include Chicago, Cleveland, Detroit, Indianapolis, Milwaukee, St. Louis, Cincinnati, Kansas City, and Minneapolis- St. Paul (GCRP 2014 citing U.S. Department of Commerce 2013). The region is in the middle of the North American continent with four major urban areas situated on the shores of the Great Lakes, the largest lake system in the world and a defining feature of the region (Gronewold and Stow 2014).

In the next few decades, climate change is expected to exacerbate existing climate-related risks to the Midwest region, including increase the frequency and intensity of extreme weather events, heat waves, and flooding events; change the composition of forests by driving the tree fauna northward; and catalyze threats to the Great Lakes, which include changes in range and distribution of aquatic species, increased persistence of invasive species and algal blooms, and declining beach health. These climate change impacts will have detrimental impacts on the region's agricultural productivity, human health, infrastructure, and ecosystems.

5.5.3.3.1 Observed and Projected Changes in Exposure

Overall temperatures in the Midwest have warmed in the past century by 1.5°F at a rate of 0.14°F per decade from 1901 to 2005. Recently, this warming rate has accelerated to 0.49°F per decade for 1979 to 2005 (Kunkel et al. 2013c citing Trenberth et al. 2007). From 1895 to 2012, average temperatures increased about 1.6°F. Average temperatures for the region are projected to continue to warm over the next few decades (2021 to 2050) by an additional 1.8°C (3.2°F) for a lower (B1) emissions scenario to 4.3°C (7.74°F) for a higher (A2) emissions scenario relative to the 1979 to 2000 period.[74] By the end of this century, average temperatures could increase between 2.7°C (4.9°F) to 4.7°C (8.5°F), for the lower (B1) and higher (A2) emissions scenarios, respectively (Kunkel et al. 2013c).

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[74] These projections are based on the WCRP CMIP3 dataset.

For ten Midwest cities, the number of hot humid days in the summer has increased over the period of 1940 to 2010, while the presence of cold dry air has decreased (Vanos et al. 2014). In addition, major heat waves have become more frequent over the last 6 decades (GCRP 2014 citing Luber and McGeehin 2008). This trend is projected to continue as heat waves become longer, more frequent, and severe (EPA 2009, GCRP 2014 citing Luber and McGeehin 2008). Warming has also been notable during the winter, where the annual frost-free period has lengthened by about 2 to 3 weeks in recent decades (Kunkel et al.2013, EPA 2009, GCRP 2014). By the end of the century, parts of the Midwest may experience increases in extreme temperatures from 7 to 10°F relative to present day conditions assuming no GHG mitigation (EPA 2015a).[75]

Generally for the region, the annual precipitation has increased up to 20 percent in the last century with heavy precipitation events accounting for much of this increase (GCRP 2014 citing Pryor et al. 2009). From 1895 to 2011, observations suggest an increasing trend in annual precipitation of 0.31 inches per decade, with a statistically significant trend observed during summer (June, July, August) (Kunkel et al. 2013c). Though there is large variability across the climate models, averaging the climate model projections suggest annual precipitation will continue to increase, more notably toward the north, with an intensification of the heaviest precipitation events throughout the region (Kunkel et al. 2013c, GCRP 2014 citing Pryor et al. 2013 and Schoof et al. 2010). By the end of the century and under the higher (A2) emissions scenario, the majority of the climate models suggest continued increases in precipitation during the winter and spring relative to 1971 to 2000 (GCRP 2014). For mid-century, regional climate models suggest an increase in springtime precipitation and a decrease in summertime precipitation relative to 1971 to 2000 under the higher (A2) emissions scenario, particularly for the southern Midwest (GCRP 2014 citing Pryor et al. 2013). For the entire Midwest, a greater portion of precipitation is projected by both global and regional climate models to fall in more frequent and more intense extreme precipitation events, which now occur twice as frequently as a century ago (EPA 2009, GCRP 2014). Extreme precipitation events can have deleterious impacts on agricultural productivity, infrastructure, and ecosystems (Kunkel et al. 2013c, GCRP 2014 citing Pryor and Barthelmie 2013).

The Great Lakes have already started to experience increases in water temperatures and reductions in ice cover. Between 1968 and 2002, summer temperatures in Lake Huron increased by 5.2°F, Lake Ontario increased by 2.7°F, and Lake Superior increased by 4.5°F (GCRP 2014 citing Dobiesz and Lester 2009, Austin and Colman 2007). By 2050, the lakes are expected to increase in surface temperatures by as much as 7°F, and by 2100, as much as 12.1°F. The average annual ice coverage from 2003 to 2013 was lower than any other decade with recorded measurements, with an average of 43 percent coverage compared to the 52 percent average coverage from 1962 to 2013, although assumptions are based on surface area and vary substantially year to year (GCRP 2014 citing Bai and Wang 2012). Measurements in the Midwest indicate that, in addition to percent coverage, the duration of ice cover has also been decreasing in the past century (Kunkel et al. 2013c).

Table 5.5.3-3 summarizes the observed and projected trends for climate variables in the Midwest and the associated resources the trends will affect.

[75] Extreme temperatures represent extremely hot days and extremely cold days. Extremely hot days are defined as those with a daily minimum temperature warmer than 99 percent of the days in the period 1989–2000. Extremely cold days are defined as those with a daily maximum temperature colder than 99 percent of the days in the period 1989–2000.

Table 5.5.3-3. Observed and Projected Trends in Environmental Variables for the Midwest

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Over the past century, increasing annual average temperatures by about 0.9°C (1.5°F) per year with accelerated rate of warming in the most recent decades.	Increase in annual average temperatures, which is most notable during winter months; increase in humidity; increase in the severity, frequency, and duration of heat waves.	▪ Terrestrial and freshwater ecosystems ▪ Food, fiber, and forest products ▪ Human health
Precipitation	Over the past century, up to a 20% increase in annual precipitation with heavy precipitation events accounting for much of this increase.	Increase in precipitation, during winter and spring. Projected intensification and increased frequency of extreme precipitation events.	▪ Terrestrial and freshwater ecosystems ▪ Food, fiber, and forest products ▪ Urban areas ▪ Human health

Notes:
Sources: EPA 2009; GCRP citing Kunkel et al. 2013c, Pryor and Barthelmie 2013, Pan et al. 2009, and Pryor et al. 2009.

5.5.3.3.2 Terrestrial and Freshwater Ecosystems

The Midwest is rich with native flora and fauna diversity within the region's prairies, wetlands, lakes, streams, and forests (GCRP 2014 citing Bischof et al. 2013). Many of the native species and ecosystems, however, are vulnerable to climate change impacts. Traits that increase a species' vulnerability to climate change include a low range of physiological tolerance, dependence on isolated habitats, dependence on relationships with other species, limitations in dispersal, low reproduction rates, and low genetic variability (GCRP 2014 citing Brook et al. 2008). When species are faced with potentially lethal impacts from climate change, they must move or adapt to survive; however, if fauna were to migrate to survive from rising temperatures, the flat terrain would require fauna to travel up to 90 miles north to reach climates 1.8°F cooler (EPA 2009, GCRP 2014 citing Jump et al. 2009).

With regard to flora, many forests will change in composition due to the rising temperatures. In both a lower (B1) emissions scenario and a high (A1FI) emissions scenario, habitats for native tree species, such as birches, aspens, and cypress will continue declining in northern forests as oak and pine forests may expand northward. These trends are projected more dramatically for the higher emissions scenario (GCRP 2014 citing Prasad et al. 2007). Results from high (A1FI) emissions scenarios indicate an overall pattern of reductions in flora diversity in higher temperatures and less productive soils (Duveneck et al. 2014).

The combination of increasing temperature and precipitation, as well as decreases in ice cover, all threaten ecosystem health within the Great Lakes. Warmer temperatures have been observed to advance the pervasiveness of invasive species in the Great Lakes system, including sea lamprey, rainbow smelt, and other non-native species (GCRP 2014 citing Bronte et al. 2003). Meanwhile, the habitat for cold water fish is expected to generally shrink, drastically altering the dispersal of fish species in the Great Lakes system, including lake trout and whitefish (EPA 2009, GCRP 2014 citing Austin and Colman 2007). Increasing temperatures will also increase the pervasiveness of algal blooms, which can cause "dead-zones" by depleting oxygen levels in the water that can "choke" fish and other aquatic plant species (EPA 2009). Lower oxygen levels in the lakes due to warmer water and increased algae can also increase persistence of mercury and other pollutants in the aquatic environment (EPA 2009).

5.5.3.3.3 Food, Fiber, and Forest Products

Anomalous weather events, higher temperatures, and changes in precipitation tend to have mixed impacts on agriculture in the Midwest, though generally, climate change impacts are detrimental to agricultural productivity (IPCC 2013 citing Hatfield et al. 2013). While higher temperatures, increased atmospheric CO_2 concentrations, and longer growing seasons from climate change have the potential to increase agricultural productivity, the increased productivity potential is offset by the freeze damage associated with the continued springtime cold air outbreaks projected throughout this century (GCRP 2014 citing Vavrus et al. 2006 and Gu et al. 2008). Heat waves during pollination and wetter springs also have the potential to reduce productivity of some crops (GCRP citing Hatfield et al. 2011 and Rosenzweig et al. 2002).

Climate change impacts vary by crop species. For instance, corn and soybeans, which make up about 85 percent of Midwest crop yields, will probably be affected very differently over the coming century (GCRP 2014 citing National Agricultural Statistics Service 2012). For corn, small long-term increases in temperatures may result in reduced reproductive development and smaller yields. For soybeans, yields might initially increase from CO_2 fertilization, however, the yields of corn and soybeans will decrease later in the century from temperature stresses (GCRP 2014 citing Parris et al. 2012, Yin et al. 2009, and Horton et al. 2011). By the end of the century, irrigated soybean yields may decrease by 23 percent relative to today assuming no mitigation of GHG (EPA 2015a). While the days without precipitation are projected to increase, extreme precipitation events are projected to increase as well, leading to droughts and flooding that could both add further stress to crop yields. The livestock industry will also face productivity threats due to the higher prices of crops (from lower yields) and increased temperatures (EPA 2009).

5.5.3.3.4 Urban Areas

Much of the Midwest population lives in urban areas, where climate change may exacerbate urban heat island effects, water cycle variability, exposure to diseases, threats to aging infrastructure, and impediments to urban services such as transportation, energy, and potable water. Heat waves, which have increased in frequency and intensity in recent decades, are exacerbated in urban areas where dense populations and impermeable surfaces increase temperature variability (GCRP 2014 citing Luber and McGeehin 2008). Impervious surfaces in urban areas also create stormwater runoff, which, with increased precipitation, could increase the volume and frequency in discharges. Additional stormwater runoff will have greater potential to overwhelm sewage systems and carry contaminants into water systems, such as the Great Lakes, increasing non-point source pollution and eutrophication. Extreme precipitation events associated with climate change may also increase flooding, which can inundate many of the region’s urban infrastructure (GCRP 2014 citing Villarini 2011). In addition to the threats transportation systems face from flooding, changes in water levels of the Great Lakes may affect the shipping industry in the region by limiting the size and weight of cargo ships permitted to transport goods (GCRP 2014 citing Sousounis et al. 2000). In recent years, the Great Lakes have experienced persistent reduction in water levels and recession in shorelines (Gronewald and Stow 2014).

Rising temperatures and increased heat waves are projected to increase demands for cooling to exceed 10 gigawatts by the middle of the century, which would require about $6 billion of investments in infrastructure. In addition, higher temperatures are projected to decrease efficiency in about 95 percent of electrical infrastructure (GCRP 2014 citing Gotham et al. 2013).

5.5.3.3.5 Human Health

Rising temperatures will probably have adverse impacts on human health in the region. The increase of frequency, severity, and length of heat waves, as well as the increased summer temperatures and humidity, may result in a greater risk of heat-related deaths (EPA 2009, GCRP 2014 citing Schoof 2013). One study found a greater frequency in heat waves that have lasted as much as 3 days longer in recent decades compared to historical records (Vanos et al. 2014). In another study, Chicago was projected to have an increase of 166 heat-related deaths per year in a lower (B1) emissions scenario and 2,217 heat-related deaths per year in a higher (A2) emissions scenario from 2081 to 2100, as compared to a 1987–2005 database on mortality (GCRP 2014 citing Peng et al. 2011).

In addition to driving climate change, human-induced emissions also deplete ambient air quality and have deleterious impacts on human health. More than 20 million Midwesterners are exposed to air quality that fails to meet national standards for air quality (EPA 2009, GCRP citing Pryor and Barthelmie 2013). Air pollutants, including particulate matter and ozone caused by automobile exhaust, may cause acute respiratory symptoms. Increased summer heat waves could raise ozone levels potentially increasing the number or severity of high pollution days in the Midwest (GCRP 2014 citing Grabow et al. 2012). In addition, the increased growing season in response to rising temperatures may also increase the length of the pollen season and the risk of vector-borne diseases (GCRP 2014 citing Ziska et al. 2011).

In urban areas, increased stormwater runoff could have detrimental impacts on human health through degrading the quality of freshwater resources. Many of the urban areas have combined sewage and storm drainage systems, and therefore, as extreme precipitation events increase, there is a greater likelihood of sewage overflow and degradation to water quality (EPA 2009, GCRP 2014 citing Patz et al. 2008). The Great Lakes have experienced such sewage overflows, affecting the drinking water of 40 million people and the swimming water of 500 beaches (GCRP 2014 citing Patz et al. 2008). Under a high (A1FI) emissions scenario, one study projected the increase in storm events leading to a 120 percent increase in sewage overflows in Lake Michigan by 2100 (GCRP 2014 citing Patz et al.2008).

5.5.3.4 Great Plains

This section discusses the impacts of climate change on the Great Plains region. This region covers the area including North and South Dakota, Kansas, Montana, Nebraska, Oklahoma, Texas, and Wyoming. The Great Plains are characterized by a highly diverse climate due to the region’s large north–south extent and change of elevation (GCRP 2014). The region is vulnerable to climate-related impacts, including extreme temperatures, large variability in rainfall, and related extreme events (e.g., floods and droughts). These impacts have implications for the region’s ecosystems, freshwater resources, and agriculture.

5.5.3.4.1 Observed and Projected Changes in Exposure

Since 1906, climate in the Great Plains has been generally warmer and wetter. Eight of the ten summers in the Great Plains between 2002 through 2011 were above the 1901 to 1960 average (Kunkel et al. 2013d). States in the northern part of the region have experienced the greatest increase in long-term average temperatures, with North Dakota experiencing the fastest annual temperature increase over the last 130 years in the contiguous United States (GCRP 2014 citing Kunkel et al. 2013d). In 2011, Dallas, Houston, Austin, Oklahoma City, Wichita, among other cities in the Great Plains region all set records for the number of days recording temperatures of 100°F or higher in those cities’ recorded history (GCRP 2014). Under a lower (B2) emissions scenario, summer temperatures are expected to increase, with the number of days over 100°F projected to double in the north and quadruple in the south by mid-century (GCRP 2014).

The Great Plains are characterized by large discrepancies in precipitation patterns, with average annual precipitation greater than 50 inches in eastern Texas and Oklahoma while areas of Montana, Wyoming, and west Texas receiving less than 15 inches of rainfall a year (GCRP 2014). These precipitation patterns are projected to change, exhibiting seasonal and regional variations. Under a higher (A2) emissions scenario, winter and spring are anticipated to become wetter in the northern part of the region relative to a 1971 to 2000 baseline, while changes in the central areas are not expected to be greater than that already associated with natural variability (GCRP 2014 citing Kunkel et al. 2013d). The number of days with heavy precipitation is expected to increase by mid-century, especially in the north, and large parts of Texas and Oklahoma are projected to see longer dry spells by mid-century (GCRP 2014 citing Kunkel et al. 2013d).

Changes in these basic climate indicators point to the more frequent occurrence of extreme events such as heat waves, droughts, and floods. These trends and events will affect the region, including exacerbating its water stresses and affecting some key economic activities. Table 5.5.3-4 summarizes the projected trends for climate variables in the Great Plains and the associated resources the trends will affect.

Table 5.5.3-4. Observed and Projected Trends in Environmental Variables for the Great Plains

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Temperatures have been above the 1901 to 1906 average for the last 20 years, both annually and seasonally. Northern states in the region have experienced the greatest increases in their long-term average temperatures.	Increases throughout the region in the number of hot days with the largest increases to occur in southwest Texas; increases of 20 to 30 days for the freeze-free season.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Human health
Precipitation	Annual precipitation was greater than average the last few years except for 2011; 20th century trends in precipitation are not statistically significant for any seasons.	Winter and spring will become wetter in the northern areas, but drier in the southern areas; summer months are projected to receive less rainfall.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems

Notes:

Source: Kunkel et al. 2013d.

5.5.3.4.2 Freshwater Resources

Freshwater availability remains a large concern in the Great Plains in future projections. A study by the Bureau of Reclamation describes the regional differences in climate-related changes in U.S. streamflows. The study's analytical and modeling results for eight Bureau of Reclamation river basins indicate that the north-central region of the western United States, which includes much of the Great Plains region, is becoming wetter. The study's runoff projections indicate that cool-season runoff will increase over the 21st century for river basins in the north-central United States (Missouri) (U.S. Bureau of Reclamation 2011). Further, recent studies suggest that increases in winter runoff rather than spring runoff could affect flood control procedures already in place. In the south, a trend toward more dry days and higher temperatures will increase evaporation and decrease water supplies, increasing the stress on the water resources and irrigation (GCRP 2014).

The U.S. Great Plains was identified as one of four global vulnerability hotspots for water availability from the 2030s and beyond, where anticipated withdrawals would exceed 40 percent of freshwater resources (IPCC 2014b citing Liu et al. 2013). A warming scenario of 2.5°C (4.5°F) or greater relative to 1990 is projected to decrease the recharge of the Ogallala aquifer region (the Great Plains' most important aquifer and primary water source) by 20 percent (EPA 2009). However, 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 (U.S. Bureau of Reclamation 2011).

Warmer water temperatures could exacerbate the presence of invasive species, jeopardizing the health of existing wetlands. Warmer waters could also increase the probability of eutrophication in wetlands and water sources, thereby decreasing water quality levels (U.S. Bureau of Reclamation 2011).

5.5.3.4.3 Terrestrial and Freshwater Ecosystems

The Great Plains region is home to unique ecosystems and wildlife, with over 10 percent of its land federally or state protected. Rising temperatures have caused many plants and animals to move from habitats at increasingly faster rates, which over time may prove difficult to both the species in adapting to varied environments and to habitat communities undergoing the shifts in species (GCRP 2014 citing Chen et al. 2011, Parmesan 2007, and Samson et al. 2004)

The millions of wetlands in the North American Prairie Pothole region covering the Northern Great Plains are considered particularly vulnerable to a warmer and drier climate. The wetlands of this region are considered to be the most productive habitat for waterfowl in the world, and are estimated to support up to 80 percent of North America's ducks. Simulations suggest that in a drier climate, the most productive habitat for breeding waterfowl would shift from the center of the region in the Dakotas and southeastern Saskatchewan to the wetter eastern and northern fringes, areas that are less productive or where most wetlands have been drained, resulting in significant declines in productivity (Johnson et al. 2005).

Increased wildfires also threaten to disrupt or fundamentally alter the habitat of the Great Plains as a result of changing climate conditions. In Yellowstone National Park, the fire rotation (i.e., the number of years it would take to burn an area equal to the landscape area) for fires greater than 200 hectares is projected to decrease from 100 to 300 years to less than 30 years, possibly turning coniferous forests into woodlands and grasslands (GCRP 2014 citing Westerling et al. 2011b). Both the frequency of large wildfires and changes in fire season length have increased substantially since 1985, and are closely linked with advances in timing of spring snowmelt (Bureau of Reclamation 2011).

5.5.3.4.4 Food, Fiber, and Forest Products

Agricultural lands cover more than 70 percent of the Great Plains, representing much of the region's economic activities with a total market value of about $92 billion (GCRP citing USDA 2012). These activities are fundamentally sensitive to climate, including changes in temperature, rainfall, and extreme events. Over the last 70 years, winter wheat has been flowering 6 to 10 days earlier as a result of rising spring temperatures (GCRP 2014 citing Hu et al. 2005). There is concern that crop yields will reduce in response to warming air temperatures.

Livestock also will be affected by changing climate in the region. As a result of rising temperatures, the estimated days to slaughter-weight for swine increased by an average of 3.7 days from the baseline of 61.2 days by 2040, according to a modeling exercise based on the Canadian Global Coupled Model (CGC) projections (Walthall et al. 2012, USDA 2008). This would result in a $12.4 million in annual losses in the central United States for producers. Under the same model, time-to-slaughter weight for confined beef cattle in the central United States increased by 4.8 days above the 127-day baseline value, costing producers $43.9 million annually.

In the Great Plains region, the projected increase in drought frequency and severity will stress the region's water resources that supply water for the agriculture sector. In the southern plains, projected declines in precipitation and greater evaporation because of higher temperatures will increase stress on water resources for agriculture. Studies show the climate impacts of shifting from irrigated to dryland agriculture would reduce crop yield by roughly a factor of two (GCRP 2014 citing Colaizzi et al. 2009).

Rising temperatures can provide benefits such as a longer growing season. However, warmer winters can allow pests and invasive plants to survive the winter (GCRP 2014 citing Nardone et al. 2010).

Since 1994, winter mortality of bark beetle larvae in Wyoming has dropped from 80 to 10 percent due to mild winters (Epstein et al. 2006 citing Holsten et al. 2000). The USDA Forest Service reports that bark beetles have now affected more than 1.5 million acres in northern Colorado and southern Wyoming, killing lodgepole pines and affecting watersheds, timber production, and wildlife habitats (USFS 2008).

5.5.3.4.5 Human Health

As the climate warms throughout the Great Plains, elderly populations will become increasingly vulnerable to heat waves, particularly in warmer cities and communities with sub-standard housing (GCRP 2014 citing Longstreth 1999). Heat waves are projected to increase for this region, with the number of days over 100°F expected to double in the northern part of the region and quadruple in the southern part of the region by mid-century, even under a lower (B1) emissions scenario (GCRP 2014).

As temperatures warm, concentrations of some airborne pollutants and allergens are projected to increase (CCSP 2008c). From the southern to the northern region of the Great Plains, an increase in frost-free days has altered flowering patterns and increased the length of the pollen season for ragweed for up to 16 days between 1995 and 2009 (GCRP 2014 citing Ziska et al. 2011). Air pollution causes a number of respiratory ailments and can lead to premature death.

5.5.3.5 Southwest

The Southwest region is projected to face significant impacts from climate change. This region includes Arizona, California, Colorado, Nevada, New Mexico, and Utah. Limited water availability in this dry, warm region has resulted in more than a century of negotiations over water rights. Over the past 50 years, the timing of snowmelt and runoff has shifted earlier into the year, and 60 percent of this shift can be attributed to increased anthropogenic GHG emissions (GCRP 2014 citing Garfin et al. 2013). Temperatures in the Southwest are projected to increase by between 2 and 9.5°F by 2070 to 2099 relative to a 1971 to 1999 baseline, and across emissions scenarios. Clow (2010) found that from 1978 to 2007, a 1°C (1.8°F) to 1.5°C (2.7°F) increase in average November to January temperatures per decade contributed to Colorado snowmelt occurring 2 to 3 weeks earlier. Changes in snowmelt and runoff will likely have major impacts on the freshwater supply in the Southwest, the health of ecosystems, and human activities such as agriculture and managed lands.

5.5.3.5.1 Observed and Projected Changes in Exposure

The Southwest region is already experiencing warmer temperatures. Since 1950, temperatures have been hotter than in any period of comparable length in the past 600 years (GCRP 2014 citing Ababneh 2008, Bonfils et al. 2008, and Garfin et al. 2013). Temperatures between 2001 and 2010 were 2°F hotter than the 1901 to 2010 average; it was the hottest decade in the southwestern temperature record of 110 years (GCRP 2014 citing Garfin et al. 2013). Under the higher (A2) emissions scenario, southwestern average annual temperature is projected to increase by 2.5 to 5.5°F by 2041 to 2070 and 5.5 to 9.5°F by 2070 to 2099, all relative to a 1971 to 1999 baseline (GCRP 2014 citing Kunkel et al. 2013e). Under the lower (B1) emissions scenario, southwestern average annual temperature is projected to increase by 2.5 to 4.5°F by 2041 to 2070 and 3.5 to 5.5°F by 2070 to 2099, all relative to a 1971 to 1999 baseline (GCRP 2014 citing Kunkel et al. 2013e). Summer heat waves are projected to intensify and lengthen, while winter cold spells are expected to become less frequent (GCRP citing Gershunov et al. 2009 and Kodra et al. 2011).

Some areas in the Southwest region have undergone precipitation increases and others have experienced decreases, and the amounts and types of precipitation are expected to change further into the future (GCRP 2014 citing Garfin et al. 2013). Since the 1960s, there has been less late-winter precipitation falling as snow along with earlier snowmelt (GCRP 2014 citing Hidalgo et al. 2009 and Pierce et al. 2008). The percentage of annual precipitation falling as rain rather than snow has increased at 74 percent of the weather stations studied in the western mountains of the United States from 1949 through 2004 (EPA 2009). Precipitation that falls in the mountains as rain instead of snow reduces runoff from snowmelt during spring and summer months. From 2001 to 2010, streamflows in the Sacramento–San Joaquin river delta, the Colorado river, the Rio Grande river, and in the Great Basin have decreased by 5 to 37 percent below the 20th century average (GCRP 2014 citing Garfin et al. 2013). Under a higher (A2) emissions scenario, changes in winter and spring precipitation by the end of the century in the north, as well as summer and fall changes throughout the region, are smaller than natural variations (GCRP 2014 citing Kunkel et al. 2013e). However, precipitation in the southern part of the region is nonetheless projected to decline by between 3 and 12 percent across B1 and A2 emissions scenarios, and exhibit no change or increase in the north (Kunkel et al. 2013e). Winter and spring precipitation in the south, by contrast, is projected to decrease in the southern part of the region (GCRP 2014 citing Kunkel et al. 2013e).

Historically, drought has stressed many areas of the Southwest region; additional decreases in precipitation are anticipated to exacerbate this existing stress as future droughts become more frequent and intense (GCRP 2014, EPA 2009). On average, during drought peak years, there has been a 63 percent decline in annual runoff in the Southwest region (Cayan et al. 2010). There is some evidence of long-term drying and increase in drought severity and duration in the Southwest (National Science and Technology Council 2008) that is probably a result of decadal-scale climate variability and long-term change (EPA 2009). Changes in the amount, timing, and type of precipitation have cascading impacts on the mountain snowpack and streamflows in the region.

A reduction in late-winter and spring snowpack followed by a reduction in runoff and soil moisture will further stress water supplies (GCRP 2014 citing Cayan et al. 2010, Cayan et al. 2008, and Christensen and Lettenmaier 2006).Twenty-first century drought in the Southwest region is more extreme than any other drying conditions over the past 100 years, although not more severe than droughts of the past 2,000 years (GCRP 2014 citing Garfin et al. 2013). Simulations project more severe droughts during the second half of the century, with some lasting for 12 or more years (Cayan et al. 2010, EPA 2015g). In the absence of GHG mitigation, the number of severe and extreme droughts is projected to quadruple by 2100 compared to present day (EPA 2015g).[76]

The timing of runoff is also anticipated to change over the 21st century. Median flows are projected to decline in most major southwestern rivers by the 2050s, and in all major southwestern rivers by the 2070s (relative to 1990 to 1999). Most notably, the Rio Grande at Elephant Butte Dam and San Joaquin River at Friant Dam are projected to decline in median flow by 16 and 11 percent, respectively (GCRP 2014 citing Garfin et al. 2013).

Sea-level rise is expected to affect the California coast. Over the last century the sea level on the California coast rose between 6.7 and 7.9 inches (GCRP 2014 citing NRC 2012). However, there is much variability in sea-level trends across the U.S. western coastline, depending on such factors as local land subsidence/uplift, changes in ocean circulation, and changes in ocean salinity. Continued sea-level rise will exacerbate the impacts of high tides, storm surges, and freshwater floods, resulting in property damage and erosion at higher levels than the Southwest region currently experiences (GCRP 2014).

The rate of sea-level rise in the Southwest region is projected to accelerate, increasing the vulnerability of coastal cities and tidal ecosystems to flooding and other hazards (GCRP 2014 citing NRC 2012, Bromirski et al. 2011, Romanovsky et al. 2011, Parris et al. 2012). Sea-level rise will increase coastal erosion and flooding during high tides and storm events. Under a 16-inch rise in sea level along the California coast, which could occur in the next 50 years, coastal highways, bridges, and airports will face increased risk of flooding (GCRP 2014 citing SFBCDC 2011). Los Angeles groundwater supply and estuaries would be at risk of saltwater contamination (GCRP 2014 citing Webb and Howard 2011), and approximately 180,000 acres of shoreline in the San Francisco Bay Area would be vulnerable to inundation. In addition, 90 to 95 percent of existing tidal marshes and flats would be affected, 20 percent of which would be vulnerable to permanent submersion or erosion (BCDC 2009 citing Heberger et al. 2009).

Were sea level to increase by 3 feet, within the 1 to 4 foot range of projected global sea-level rise by the end of the century, the number of Californians at risk from a 1-in-100-year flood would increase from 260,000 to 420,000 assuming current population densities and existing exposure levels, where approximately 18 percent of this exposed population is considered highly vulnerable (GCRP 2014 citing Heberger et al. 2011, NRC 2012, Parris et al. 2012, Cooley et al. 2012). Table 5.5.3-5 summarizes the projected trends for climate variables in the Southwest and the associated resources the trends will affect.

[76] This is based on two drought indices: the Standardized Precipitation Indices (SPI-5 and SPI-12) and the Palmer Drought Severity Index (PDSI).

Table 5.5.3-5. Observed and Projected Trends in Environmental Variables for the Southwest

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Temperatures between 2001 and 2010 almost 2°F hotter than 1901 to 2010 average; temperature trends are upward and statistically significant (at the 95% level) for each season, and the year as a whole; freeze-free season about 17 days longer than in early 20th century.	Average annual temperature increase between 2 and 9.5°F by 2070 to 2099 relative to 1971 to 1999; intensified summer heat waves; decreased wintertime cold air outbreaks; greatest warming in summer in central Utah; increases in number of days above 95°F; freeze-free season increases by 17 days in most of region; more pronounced decreases in late-winter and spring snowpack; earlier occurrence of snowmelt in the year.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Human health
Precipitation	Less late-winter precipitation falling as snow; earlier snowmelt; streamflows arriving earlier in the year;	Decreased annual precipitation of between 3 and 12% in the south across lower (B1) and higher (A2) emissions scenarios, no change or increased annual precipitation across lower (B1) and higher (A2) emissions scenarios in the north; frequency and intensity of extreme dry events will increase in the second half of the century.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems
Sea level	Over the past 100 years, sea level along the California coast has risen between 6.7 and 7.9 inches.	Sea levels will threaten both managed environments, such as highways and airports, and natural environments, such as estuaries and groundwater supplies.	▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal and low-lying areas

Notes:

Sources: GCRP 2014, Kunkel et al. 2013e, Garfin et al. 2013.

5.5.3.5.2 Freshwater Resources

The major climate-related concern in the Southwest region is the availability of freshwater resources. The region has historically been faced with limited resources, large-scale agriculture, and rapid population growth. Freshwater is also critical to the health of natural ecosystems. A study by the Bureau of Reclamation (2011) found that basins in the Southwest are becoming drier. Reduced snowpack and irregular streamflow are two major driving factors in the availability of freshwater in the Southwest. Anthropogenic climate change has resulted in earlier peak flow of snowmelt runoff and declines in water stored in snowpack in the western United States (IPCC 2014c). Climate change is projected to further reduce snowpack and streamflow (GCRP 2014). There is a trend toward earlier spring snowmelt across much of the western United States. Across broad areas of the southwest (Colorado, Utah, northern Arizona, Wyoming, Idaho, Washington, and Southern California), snow-fed streamflows have arrived between 5 and 20 days earlier in the past decade relative to a 1950 to 2000 average (GCRP 2014 citing Garfin et al. 2013). Over the last century, stream discharge in the Rocky Mountain region has decreased by about 2 percent per decade (EPA 2009). By 2100, seven of ten Rocky Mountain Creeks modeled by St. Jacques et al. (2013) demonstrate decreased streamflow under a higher (A2) emissions scenario. According to EPA (2009), loss of snowpack in the Sierra Nevada and Colorado River Basin could leave 41 percent of the water supply in southern California vulnerable by the 2020s.

Snow water equivalent (SWE), which describes the amount of water stored in a given volume of snow, provides a high correlation with early runoff and decreases in total runoff. Thus, projected changes in SWE inform future water availability in the Southwest region (GCRP 2014). Under a moderately high (A2) emissions scenario, Colorado, which contributes the greatest volume of snow to the Southwest, is projected to experience a reduction in SWE of 26 percent below the 1971 to 2000 average level by 2070 to 2099. SWE in California and Utah, the next two largest snow contributors to the Southwest, is projected to decrease by 57 and 44 percent below the 1971 to 2000 average by 2070 to 2099, respectively. While Arizona, Nevada, and New Mexico contribute far less snow to the regional total, declines in SWE are projected to experience greater percent change (88 percent, 69 percent, and 66 percent below the 1971 to 2000 average by 2070 to 2099, respectively) (GCRP 2014), which could present greater challenges for Arizona, Nevada, and New Mexico relative to the rest of the Southwest.

By the end of the century, projections of water quality for rivers and lakes suggest a substantial decline of 15 to 26 percent compared to today's conditions assuming no GHG mitigation (EPA 2015g).[77] Under this scenario, the Southwest is projected to experience water quality damages of approximately US$1.8 billion by the end of the century (EPA 2015g).

These additional strains on freshwater resources would have significant implications not only for freshwater resources but also for hydroelectric generation, agriculture, land use, and water management. A reduced water supply also will likely add conflict to the already contentious water rights issues in the region. Federal agencies have identified a number of areas, mostly in the West, where conflicts could arise over growing water shortages (DOI 2005, Brekke et al. 2009).

5.5.3.5.3 Terrestrial and Freshwater Ecosystems

Plant and animal species in the northern hemisphere are shifting ranges to the north and west and to higher elevations (Grimm et al. 2013). Many species could shift ranges so extensively by 2100 that they might alter biome composition across 5 to 20 percent of the United States (with a large number of these species residing in the southwestern United States) (Grimm et al. 2013). The following paragraphs provide examples of plant species, animal species, and ecosystems in the Southwest that have been observed or projected to be affected by changes in climate.

Regional tree dieback could convert temperate woodlands into temperate grasslands, which would decrease standing biomass, carbon content, net primary productivity, radiation-use efficiency, canopy closure, and leaf area (Grimm et al. 2013). The lower bound of the elevation range of half of the 28 mammal species in Yosemite National Park in California moved approximately 500 meters (1,640 feet) upward since they were first studied a century ago (Pimm 2009 citing Moritz et al. 2008).

Alpine meadow systems in the southern Rocky Mountains have shifted the timing of flowering from a unimodal peak, lasting most of the summer, to bimodal peaks. This has led to a reduction in the total number of mid-summer flowers. A shift in the timing and abundance of flowers might not coincide with traditional pollinators (Aldridge et al. 2011). If nectar is a primary food source for the pollinators, the shift could result in a cycle of declining flowers and pollinators. Further, Kelly and Goulden (2008) documented dominant plant species in the Santa Rosa Mountains in Southern California increasing their average elevation by about 65 meters (213 feet) between an initial observation in 1977 and a follow-up

[77] Water quality is based on the water quality index (WQI) that includes several key water quality constituents such as temperature, dissolved oxygen, total nitrogen, and total phosphorus.

examination in 2006 to 2007. The authors rule out air pollution or wildfires as determinant factors in their range shift, concluding that regional climate change is the stressor.

5.5.3.5.4 Food, Fiber, and Forest Products

Warmer temperatures and less precipitation will affect the diversity, type, and health of forests in the Southwest region. Bioclimatic modeling indicates a future decline in the diversity of tree species in the Southwest region. A recent study analyzing tree ring patterns concluded that the projected temperature increase, which is a significant driver of tree mortality events like the current southwestern drought (the worst drought since the late 1500s), will cause the average drought in the 2050s to be worse than the most severe droughts of the past 1000 years. Further, because many species dependent on southwestern forests have limited ability to adapt to climate change, temperature projections would result in species distributions quite different from what we observe today (Williams et al. 2013).

Temperature increases, drought, insect infestations, and accumulation of woody fuels and non-native grasses contribute to the Southwest region's vulnerability to wildfire (GCRP 2014 citing Bonfils et al. 2008, Williams et al. 2010, Abatzoglou and Kolden 2011, and Moritz et al. 2012). From 1916 to 2004, climate change was more pivotal than all other factors in determining forest burn area (GCRP 2014 citing Littell et al. 2009, Marlon et al. 2012, Trouet et al. 2010, Swetnam 1993, Taylor and Scholl 2012, and Swetnam et al. 2009). Between 1970 and 2003, warmer temperatures and arid conditions resulted in a 650 percent increase in burn area in the western United States mid-elevation conifer forests (GCRP 2014 citing Westerling et al. 2006). In addition to drought and higher temperatures, climate change-fueled increases in bark beetle and pine beetle outbreaks have been linked to declines in certain tree species. For example, wildfire coupled with bark beetle infestations have killed trees across 20 percent of Arizona and New Mexico forests from 1984 to 2008 (GCRP 2014 citing Williams et al. 2010).

As climate change intensifies, wildfires are projected to increase. By the end of century, burn area is projected to double in the Southern Rockies (GCRP 2014 citing Litschert et al. 2012), to increase 74 percent in California as a whole, and potentially double in northern California under a moderately high (A2) emissions scenario (GCRP 2014 citing Westerling et al. 2011a). Assuming no GHG mitigation, Arizona, New Mexico, and West Texas are collectively projected to experience an average increase in burned areas of 140 percent by the end of the century compared to present day (EPA 2015g). Furthermore, increased wildfires will contribute to vegetation shifting upslope, increased prevalence of invasive plants, and conversions of forests to woodland or grassland (GCRP 2014 citing Abatzoglou and Kolden 2011 and Allen and Breshears 1998). Forty percent of the Southwest region is projected to become vulnerable to vegetation shifts under a moderately high (A2) emissions scenario (GCRP 2014 citing Gonzalez et al. 2010).

Excluding Colorado, more than 92 percent of southwestern cropland is irrigated, and the agricultural sector is responsible for nearly 80 percent of all water withdrawals (GCRP 2014). It follows that farmland in the Southwest region—specifically in California, which produces roughly 95 percent of many high-value crops grown in the United States such as apricots, almonds, pistachios, and olives (GCRP 2014 citing Beach et al. 2010)—is projected to become increasingly vulnerable to the impacts of climate change. Longer frost-free seasons, less-frequent cold air outbreaks, and more frequent heat waves are expected to reduce corn, tree fruit, and grape yields, stress livestock production, and increase agricultural water consumption (GCRP 2014 citing Baldocchi and Wong 2008, Lobell et al. 2006, Purkey et al. 2008, and Battisti and Naylor 2009). Additionally, certain warm-season vegetable crops in California may not be viable in increasingly hot temperatures (GCRP 2014 citing Jackson et al. 2012 and Jackson et al. 2011).

5.5.3.5.5 Human Health

The Southwest region's urban population rate of 92.7 percent (i.e., the percentage of the total population living within a city) is the highest in the United States, and contributes to increased vulnerability to climate impacts (GCRP 2014 citing U.S. Census Bureau 2012b, California Department of Water Resources 2009, Ray et al. 2008, and Gleick 2010). Rising temperatures increase urban demand for vegetation to reduce the urban heat island effect, yet population growth will concurrently compete for water supplies. High temperatures also increase demand for air conditioning, which strains power systems already vulnerable to small disruptions. For example, in 2011 an 11-minute disturbance eventually led to 1.5 million people in San Diego without power for 12 hours (GCRP 2014 citing FERC and NAERC 2012). Powerless water treatment facilities were then unable to prevent the release of 1.9 million gallons of sewage onto nearby beaches (GCRP 2014 citing Medina 2011). Such strains on the power grid can lead to illness and death among at-risk populations, such as the elderly and minorities.

Heat waves result in large numbers of fatalities; a conservative estimate of deaths from a 2006 heat wave in California totaled 147 (Ostro et al. 2009). Increased frequency, duration, and intensity of heat waves in the southeast are projected to increase the number of fatalities from heat stress, which is the leading weather-related cause of death in the United States (GCRP 2014 citing NWS 2012, Gershunov et al. 2009, Gershunov et al. 2011, Sheridan et al. 2011, Sheridan et al. 2012a, and Sheridan et al. 2012b). Additionally, heat waves can exacerbate existing human health conditions, such as respiratory and heart disease, by increasing ozone formation (GCRP 2014 citing Ostro et al. 2011).

5.5.3.6 Northwest

This section discusses the impacts of climate change in the Northwest region—Idaho, Oregon, and Washington. This region has a varied topography and climate that includes shorelines, mountains, and desert. Key natural resources in the region are vulnerable to a range of climate hazards that will change as temperatures increase, precipitation patterns shift, and sea levels rise. As a result, the region may face water-related challenges, coastal vulnerabilities, impacts on forests, and changes in agricultural productivity. This section focuses on the climate impacts that are anticipated to affect the Northwest uniquely. General impacts such as the implications of extreme heat and air quality concerns on human health are addressed in the respective chapters.

5.5.3.6.1 Observed and Projected Changes in Exposure

The Northwest has observed increases in temperature, changes in precipitation patterns (that are less noticeable when compared to natural variation), and changes in the relative sea level. From 1895 to 2011, temperatures across the region have increased by 1.3°F with a notable increase in the number of recent heat waves (GCRP 2014 citing Kunkel et al. 2013f). Though there has not been a statistically significant change in annual precipitation from 1895 to 2011, there has been an increase in the variability of annual precipitation since 1976 when compared to the previous 75 years (Kunkel et al. 2013f). Sea level along much of the Northwest coastline has been falling due to "tectonic uplift" resulting in less observed sea-level rise than the global average (GCRP 2014); though some Puget Sound locations are experiencing subsidence and thus higher than average relative sea-level rise.

By end of century, average annual temperatures for the region is projected to increase by 3.3 to 9.7°F for lower (B1) to higher (A2) emissions scenarios compared to the 1970 to 1999 period, with summer experiencing the largest seasonal increase (GCRP 2014). Under the higher (A2) emissions scenario, the number of days with maximum temperatures exceeding 95°F are modeled to increase by as much as 18 days annually in southern Idaho for the 2041 to 2070 period compared to the 1990 to 2000 baseline (Kunkel et al. 2013f). Projections for precipitation are less certain with large variations of wetter to drier conditions projected across climate models and emissions scenarios. By mid-century, annual precipitation projections suggest a range of plausible futures from an 11 percent decrease to a 12 percent increase relative to 1970 to 1999 (based on an ensemble of projections from 21 climate models and the low [B1] and moderate [A1B] emissions scenarios) (GCRP 2014 citing Mote et al. 2010a). By the end of the century, the annual precipitation projections for the region ranges from a 10 percent decrease to an 18 percent increase relative to the 1970 to 1999 baseline (GCRP 2014 citing Mote et al. 2010a).

The area-averaged snowpack on April 1 in the Cascade Mountains has decreased by approximately 20 percent since around 1950 (GCRP 2014 citing Mote 2006). This shift, driven by warmer temperatures, has resulted in an earlier spring snowmelt that occurred 0 to 30 days earlier than historical trends, depending on location (GCRP 2014 citing Stewart et al. 2005). The warming trend resulted in some areas experiencing a shift in the timing of snowmelt from summer to late winter/early spring. Since about 1950, snow-fed streamflow increased from 0 to 20 percent as a fraction of annual flow in the late winter/early spring (GCRP 2014 citing Stewart et al. 2005) and decreased in summer flows from 0 to 15 percent as a fraction of annual flow (GCRP 2014 citing Stewart et al. 2005). Snowmelt is projected to continue to shift 3 to 4 weeks earlier than the 20th century average with substantial reductions for summer flows by 2050 (GCRP 2014 citing Elsner et al. 2010). Models project basins with a significant snowmelt will experience reductions in summer flows by 2050, under all emissions scenarios considered in the NCA report (GCRP 2014 citing Elsner et al. 2010).

Warming is projected to increase river-related flood risk in most basins that have runoff peaks related to winter rainfall and spring snowmelt. Snow-dominant basins (i.e., where runoff is fed predominantly by snowmelt) are expected to remain largely unchanged with regard to river-related flooding (GCRP 2014 citing Mantua et al. 2010).

Models suggest that the number of days with more than 1 inch of precipitation in eastern Washington, Oregon, and northern Idaho will increase between the period of 2041 to 2070 and the 1980 to 2000 reference period. However, there is no statistically significant indication of a trend for the region (Kunkel et al. 2013f). Rain-snow and rain-dominant basins may experience an increase in flood risk resulting from an increase in heavy downpours (GCRP 2014).

Table 5.5.3-6 summarizes the observed and projected trends for climate variables in the Northwest and the associated resources the trends will affect.

Table 5.5.3-6. Observed and Projected Trends in Environmental Variables for the Northwest

Environmental Variables	Observed Trend	Projected Trend	Affected Resource
Temperature	From 1895 to 2011, an increase in average temperatures of 1.3°F; generally low frequency of extreme cold periods since 1990 compared to the number of intense cold wave events since 1895.	2070 to 2090 projected average annual temperature increase 3.3 to 9.7°F for lower (B1) to higher (A2) emissions scenarios compared to the 1970 to 1999 period; seasonal temperature increase is projected to be largest during the summer.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems
Precipitation	Since 1976, annual precipitation has demonstrated high variability as compared to the previous 75 years. There has not been a statistically significant increase or decrease in precipitation during the 1895 to 2011 period. Changes to "extreme" events have not been statistically significant.	Large variation in annual precipitation changes across climate models and emissions scenarios, with projections ranging from wetter to drier conditions.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal, and low-lying areas
Sea-Level Rise	Much of the Northwest coastline is rising due to "tectonic uplift" resulting in less observed sea-level rise than the global average. Some Puget Sound locations are experiencing subsidence and thus higher than average relative sea-level rise.	Global sea levels are projected to rise another 1 to 4 feet by 2100.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal, and low-lying areas

Notes:
Sources: GCRP 2014, Kunkel et al. 2013f.

5.5.3.6.2 Freshwater Resources

Climate change is projected to affect the timing and availability of freshwater resources in the Northwest. Although the annual amount of precipitation might remain relatively constant, population growth, increased temperatures, and the timing and type of precipitation are anticipated to stress the availability of sufficient freshwater. Water resources are essential across several competing uses, including irrigation, municipal and industrial use, hydropower production, and preservation of aquatic habitat. Further irrigation needs for crops could increase as earlier snowmelt leads to reduced spring soil moisture (GCRP 2014 citing Kunkel et al. 2013f; Bureau of Reclamation 2011). Reduced summer flows in basins with significant snowmelt will increase tension between the various uses. For example, demand for electric cooling, crops, and forests will increase simultaneously as the water resources become more scare in the summer months (GCRP 2014 citing Hamlet et al. 2010 and Kunkel et al. 2013f; Bureau of Reclamation 2011).

5.5.3.6.3 Food, Fiber, and Forest Products

Higher temperatures and increased water deficits are expected to increase the number and extent of wildfires, promote the survival of invasive species, and shift the locations and diversity of forests (GCRP 2014). Water deficits increase tree stress, mortality, and vulnerability to insects, which can result in increased fuel for wildfires (GCRP 2014 citing Littell et al. 2012 and McKenzie et al. 2008). The number and extent of wildfires has increased in the forests of the western United States since the 1970s; the changes are associated with the timing of spring snowmelt (Westerling et al. 2006). An increase in wildfires could increase the threat of respiratory and cardiovascular illnesses in nearby populations (GCRP 2014 citing McKenney et al. 2011).

Increased disturbance and changes in forest extent and composition will result in changes to forest ecosystems upon which native species rely. Models suggest that subalpine and alpine ecosystems may convert to completely different vegetation types by the 2080s (GCRP 2014 citing Lenihan et al. 2008, Rogers et al. 2011, and Rehfeldt et al. 2012). These forest changes are expected to have an economic impact on the region, the greatest impact of which experience by the local timber and bioenergy markets (GCRP 2014 citing Capalbo et al. 2010).

Agriculture in the Northwest is projected to experience some short-term benefits but also face new obstacles with warmer temperatures, water deficits, changes in precipitation patterns, and shifts in the growing season (GCRP 2014). Agricultural commodities and food production systems contributed 14 percent of the region's 2009 gross domestic product (GCRP 2014 citing Brady and Taylor 2011). While a longer growing season and higher atmospheric CO_2 may benefit some crops in the short term (GCRP 2014 citing Stöckle et al. 2010 and Hatfield et al. 2011), warmer temperatures may negatively affect crops that are sensitive to heat stress, and water deficits may limit the water available for irrigation (GCRP 2014 citing Elsner et al. 2010). With regard to pests, higher average temperatures are associated with expanded geographic ranges, earlier emergence or arrival, and increased numbers of pests in some areas, which can negatively affect agricultural production (GCRP 2014 citing Parmesan 2006). Region-wide generalizations cannot be made since specific trends among pathogen and pest species react to a range of interactions (GCRP 2014 citing Juroszek and Tiedemann 2013).

Shellfish harvests in the Pacific Northwest are currently being adversely impacted by acidification (EPA 2015g). In the absence of GHG mitigation, the U.S. supplies of oysters, clams, and scallops could decline by 45, 35, and 48 percent, respectively (EPA 2015g).

5.5.3.6.4 Terrestrial and Freshwater Ecosystems

Changes in streamflow and water temperatures can affect stream ecology. In the Northwest, stream habitat is critical to the survival of several coldwater fish species, including salmon, steelhead, and trout. Rising stream temperatures increase disease and/or mortality in several salmon species, especially for spring/summer Chinook and sockeye (GCRP 2014 citing Crozier et al. 2008). Although the contribution of snowmelt to the streams may regulate temperature increases in the short term (GCRP 2014 citing Rieman and Isaak 2010), a decline in snowpack could eventually cause water temperatures to increase (GCRP 2014 citing Wenger et al. 2011). Compared to the period 1978 to 1997, suitable habitat for the four trout species in the interior region is projected to decline 47 percent on average by the 2080s, due to a combination of increases in temperatures, negative biotic interactions, and increases in winter flood frequency caused by warmer, rainier winters (Wenger et al. 2011).

Warmer lake temperatures also have been linked to earlier blooms of algae, which can disrupt the bottom of the food chain that can cascade up to larger, even keystone, species (GCRP 2014 citing

Winder and Schindler 2004). Shifts in habitat and ecological conditions may lead to mismatches such as the availability of food sources (GCRP 2014 citing Winder and Schindler 2004).

5.5.3.6.5 Ocean Systems, Coastal, and Low-lying Areas

The Oregon and Washington coasts provide both natural resources and human uses that are important to the region for both economic and recreational reasons. Coastal and marine ecosystems are located along beaches, rocky shorelines, bluffs, and estuaries. Human uses include international ports and transportation systems that support rural and dense urban communities along the coast and throughout the region (GCRP 2014). Sea-level rise, erosion, inundation, and changes to the ocean chemistry pose a major threat to these critical costal resources.

The Northwest coastal waters are some of the most productive waters on the West Coast (GCRP 2014 citing Hickey and Banas 2008). Currently, the regional conditions and relative productivity are influenced by a variety of factors including sea surface temperatures, ocean acidity, and coastal upwelling, which may be influenced by climate change:

- Coastal inundation: As sea levels rise, coastal wetlands, tidal flats and beaches may experience more frequent inundation because more than 140,000 acres of these coastal lands lie less than 3.3 feet above high tide (GCRP 2014 citing Strauss et al. 2012). Species such as shorebirds and small fish that rely on these coastal habitats would be at greater risk from a decline in habitat availability and quality (GCRP 2014).
- Ocean acidification: Ocean waters are projected to become more acidic but acidity levels will vary by season and location (GCRP 2014 citing Feely et al. 2010, Feely et al. 2012, and Feely et al. 2008). Culturally and commercially important marine species, such as oysters and Pacific salmon are threatened either directly by changes in ocean chemistry or indirectly through changes in the food chain (GCRP 2014 citing Ries et al. 2009).
- Warmer ocean temperatures: Surface water temperatures are projected to increase 2.2°F during the 2030 to 2059 period, as compared to a 1970 to 1999 baseline, averaged across 20 climate models under the low (B1) and moderate (A1B) emissions scenarios (GCRP 2014 citing Mote et al. 2010). Warmer water temperatures and ecological conditions may affect the location, type, and survival of marine species (GCRP 2014 citing Hollowed et al. 2001 and Tillmann and Siemann 2011). Warming temperatures have coincided with the arrival of subtropical and offshore marine species that are more common to the waters of Baja (GCRP 2014 citing Pearcy 2002). Regional estuaries, such as Puget Sound, may experience higher incidence of harmful algal blooms from warmer temperatures. The algal blooms are linked to paralytic shellfish poisoning (GCRP 2014 citing Moore et al. 2009) and could have negative economic impacts (GCRP 2014 citing Dyson and Huppert 2010).

In addition to the natural productivity of the coast, it supports many human uses for living, working, and recreation. Inundation from sea-level rise could affect essential industrial and community assets such as wastewater treatment plants (GCRP 2014 citing Solecki and Rosenzweig 2012 and King County Department of Natural Resources and Parks 2008); stormwater outfalls (GCRP 2014 citing Fleming and Rufo-Hill 2012 and Simpson 2011); ferry terminals (GCRP 2014 citing WSDOT 2011); and transportation networks, especially those in Puget Sound (GCRP 2014 citing MacArthur et al. 2012).

5.5.3.7 Alaska

This section focuses on the climate impacts anticipated to continue to affect Alaska. Alaska has marine, tundra, boreal forest, and rainforest ecosystems that are unique to this Arctic region and remain relatively intact. The region provides critical habitat for migratory birds, iconic caribou, fish, and marine mammals. The economy is driven by energy production, with mining, fishing, and tourism rounding out the top four industries (GCRP 2014 citing Leask et al. 2001). The region is home to 229 of the 566 federally recognized tribes in the United States (BIA 2014). Key climate change vulnerabilities in Alaska include declining sea ice, disappearing glaciers, thawing permafrost, changes in ocean temperature and chemistry, and impacts on the land and resources upon which native communities depend. These changes have significant impacts on freshwater resources; food, fiber, and forest products; terrestrial and freshwater ecosystems; ocean systems, coastal, and low-lying areas; urban areas; rural areas; and human security.

5.5.3.7.1 Observed and Projected Changes in Exposure

Alaska's large and diverse land area contributes to significant variations in climatic conditions. The climate is primarily influenced by latitude, altitude, proximity to the ocean, and the seasonal distribution of sea ice. Average annual temperatures can vary widely across the state, ranging from as low as -20°C (-4°F) in the northern latitudes to 11°C (52°F) in the southern coastal regions, as illustrated by the map in Figure 5.5.3-1 (Stewart et al. 2013). The temperature range between summer highs and winter lows is much greater in interior Alaska where the difference can be as much as 90°F. In contrast, southern areas are tempered by the maritime influence and have a much smaller inter-seasonal range on the order of 30 to 40°F (Stewart et al. 2013 citing Shulski and Wendler 2007).

Figure 5.5.3-1. Average Annual Temperature (°C) in Alaska

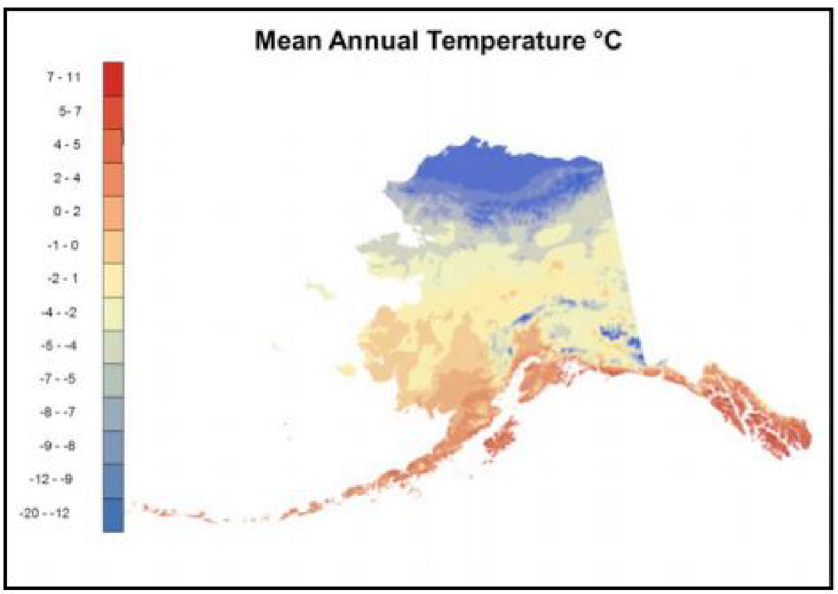

Figure 2. Mean annual temperature (°C) in Alaska for 2000-2009. Maps were produced by the Scenarios Network for Alaska Planning (SNAP) at the University of Alaska Fairbanks using data from the Climatic Research Unit (CRU) at the University of East Anglia, downscaled using the base climatology produced by the PRISM Climate Group at Oregon State University.

Source: Stewart et al. 2013.

Between 1949 and 2011, annual temperatures across Alaska increased an average of 3.0°F, with warming nearly twice as high in winter, increasing an average of 5.8°F, with substantial year-to-year variability (Stewart et al. 2013). Some communities, such as Big Delta in the Arctic interior, have experienced average winter temperature increases by as much as 9°F (Stewart et al. 2013). Alaska has experienced more days of extreme heat and fewer days of extreme cold with most anomalies representing a warming pattern since 1976 (GCRP 2014 citing CCSP 2008 and Stewart et al. 2013). By 2050, average annual temperatures in Alaska are projected to increase 2 to 4°F above a 1971 through 1999 baseline (GCRP 2014). This reflects a projected increase of 1.6 to 4.4°F under the low (B1) emissions scenario and an increase of 1.8 to 5.5°F under the high (A2) emissions scenario by 2050 (Stewart et al. 2013). The higher end of the projected range covers a larger geographic region under the high (A2) emissions scenario, nearly entirely in higher latitudes, as compared to the low (B1) emissions scenario. By the end of the century, the difference in projections between the scenarios is more pronounced, where the upper range of temperature increase under the low (B1) emissions scenario increases to 7.5°F in the northern region. For the same time frame, under the high (A2) emissions scenario, the projected increase ranges from 5.5°F in the southern region to as much as 13.5°F in the most northern area of the state (Stewart et al. 2013). Projections vary for regions across the state with more rapid rates of warming are projected in the north, followed by the interior (GCRP 2014 citing Markon et al. 2012 and Stewart et al. 2013). Underlying long-term warming has moderated effects of Pacific Decadal Oscillation from shifting to its cooler phase in the early 2000s (GCRP 2014 citing Bieniek et al. 2014).

The average annual precipitation varies widely throughout the state. Figure 5.5.3-2 shows that precipitation may be limited to less than 6 inches per year in the Arctic and be as high as 200 inches annually in the coastal mountains in the southeastern panhandle (Stewart et al. 2013). From 1949 to 2005, the average statewide annual precipitation increased by approximately 10 percent, with notable regional and seasonal variation (Stewart et al. 2013 citing Shulski and Wendler 2007). All models projected an increase in precipitation during every season (Stewart et al. 2013). Annual precipitation is projected to increase 15 to 35 percent in Alaska by the end of the century, as compared to the 1971 to 1999 baseline. The greatest increases are projected to occur in the northwest region of the state, with the low (B1) emissions scenario projecting smaller increases (15 to 20 percent) in the region and the high (A2) emissions scenario projecting a greater increase (20 to 35 percent) in the northwest (Stewart et al. 2013).

Figure 5.5.3-2. Average Annual Precipitation (millimeters) in Alaska

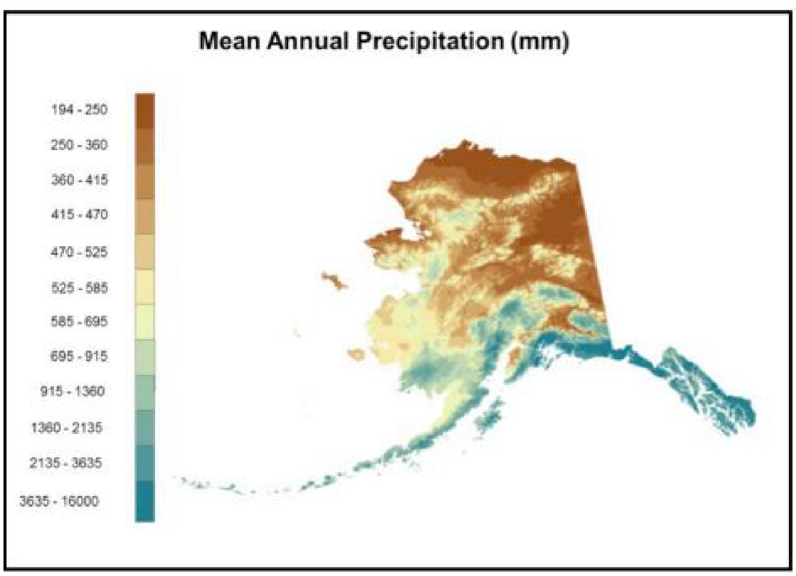

Figure 3. Mean annual precipitation (rain and melted snowfall, mm) in Alaska for 2000-2009. Maps were produced by the Scenarios Network for Alaska Planning (SNAP) at the University of Alaska Fairbanks using data from the Climatic Research Unit (CRU) at the University of East Anglia, downscaled using the base climatology produced by the PRISM Climate Group at Oregon State University.

Source: Stewart et al. 2013.

Table 5.5.3-7 summarizes the projected trends for climate variables in Alaska and the associated resources the trends will affect.

Two effects have led to the increases in average annual temperature: warmer temperatures and a self-reinforcing climate cycle, whereby warmer ocean temperatures melt more ice, creating more dark open water that absorbs even more heat, and results in the higher observed air temperature increases in the Arctic (GCRP 2014 citing Screen and Simmonds 2010). The extent and thickness of Arctic sea ice have declined substantially, and there is approximately half as much sea ice in late summer (September) as there had been when the satellite record began in 1979 (GCRP 2014 citing Maslowski et al. 2012 and Stroeve et al. 2012a). The 2006 to 2013 period represents the seven Septembers with the lowest ice extent. By 2030, models that best match historical trends indicate that the northern waters will be nearly ice-free by late summer (GCRP 2014 citing Stroeve et al. 2007 and Stroeve 2012).

Table 5.5.3-7. Observed and Projected Trends in Environmental Variables for Alaska

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Over the past 60 years, average annual temperatures have increased 3°F with greater winter warming of approximately 6°F. More days of extreme heat and fewer extremely cold days with mostly warm anomalies since 1976.	By 2050, annual average temperatures are projected to increase another 2 to 4°F compared to a 1971 to 1999 baseline. The projected increase by 2100 is 4 to 8°F under a lower emissions scenario or as high as 6 to 12°F under a higher emissions scenario. Projections vary for regions of the state.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal, and low-lying areas ▪ Urban areas
Precipitation	Average statewide annual precipitation increased approximately 10% between 1949 and 2005.	Annual precipitation is projected to increase, especially in northwestern Alaska. Under the higher emissions scenario, precipitation increases are projected to be about 15 to 35% by the end of the century, compared to a 1979 to 1999 baseline.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems
Length of the Growing Season	The length of the growing season in interior Alaska has increased 45% over the past century.	Trend is projected to continue.	▪ Freshwater resources ▪ Food, fiber, and forest products ▪ Terrestrial and freshwater ecosystems

Notes:

Sources: GCRP 2014, Stewart et al. 2013.

Near the Alaskan Arctic coast, permafrost temperatures have warmed 4 to 5°F at a 65-foot depth since the 1970s (GCRP 2014 citing Osterkamp and Romanovsky 1999 and Romanovsky et al. 2012) and 6 to 8°F since the mid-1980s at a 3.3-foot depth (GCRP 2014 citing Romanovsky et al. 2008). The trend of warming and thawing is projected to continue (GCRP 2014 citing Avis et al. 2011 and Euskirchen et al. 2006), and some models project that, by the end of the century, large parts of Alaska will completely lose near-surface permafrost (GCRP 2014 citing Jafarov et al. 2012). By the end of the century, 57 percent of the state will lose permafrost within the top 2 meters (7 feet) (IPCC 2013b citing Marchenko et al. 2008).

5.5.3.7.2 Freshwater Resources

Some of the largest and most rapidly retreating glaciers in the world are located in Alaska (GCRP 2014 citing Berthier et al. 2010, Jacob et al. 2012, and Larsen et al. 2007). The primary cause for rapid ice loss on glaciers is rising temperatures (GCRP citing Arendt et al. 2002, Arendt et al. 2009, and Oerlemans 2005). Flat, low-lying, valley glaciers, such as those in Alaska, are currently demonstrating the most rapid mass loss (IPCC 2014b). Glacial melt from Alaska and neighboring British Columbia, Canada, contributes approximately 40 to 70 gigatons of surplus freshwater to the oceans annually, about 20 to 30 percent of the amount that the Greenland ice sheet contributes (GCRP 2014 citing Jacob et al. 2012, Kaser et al. 2006, Luthcke et al. 2008, and Pelto 2011). Glacial and ice-sheet melting is predicted to be one of the largest causes of global sea-level rise in the 21st century (GCRP 2014 citing Maier et al. 2005 and Radić and Hock 2011).

About half of the freshwater input in the Gulf of Alaska comes from glacial melt (GCRP 2014 citing Neal et al. 2010). Initially, the increased melt increases river discharge and hydropower potential, however, as the size of the glaciers decrease, the long-term water input may reduce hydropower resources (GCRP 2014 citing Cherry 2010).

5.5.3.7.3 Food, Fiber, and Forestry

There are nearly 80,000 Tribal members in Alaska (BIA 2014). Alaskan Native peoples are the most numerous residents in the rural northern regions of the state, where food and fuel prices are the highest and household income is limited (GCRP 2014 citing Goldsmith 2008). Warming ambient air temperatures, warmer water temperatures, thinning sea and river ice, altered spring run-off patterns, northward shifts in the habitat range of seals and fish, and rising sea levels all threaten critical food sources and the ability to maintain basic infrastructure in communities.

Alaskan Native peoples rely on hunting and fishing for sustenance, income, and their culture (GCRP 2014 citing Cochran et al. 2013, Huntington et al. 2005, and Kruse 1991). Thinning of sea and river ice makes hunting and harvesting more dangerous (GCRP 2014 citing Berner et al. 2005). The lack of sea ice for marine mammals has placed major food sources under stress (GCRP 2014 citing Galloway McLean et al. 2009) as seal and fish species move northward (GCRP 2014 citing Davis 2012), adding additional challenges to hunting. Thawing permafrost under warming conditions introduces new diseases to plants and animals, which can further threaten food resources (GCRP 2014 citing McLaughlin et al. 2005).

Glacial melt is an important source of organic carbon (GCRP 2014 citing Bhatia et al 2010 and Hood et al. 2009), phosphorus (GCRP 2014 citing Arendt et al. 2009), and iron (GCRP 2014 citing Schroth et al. 2011). Shifts in the inputs may impact near-shore fisheries (GCRP 2014 citing Hood et al. 2009 and Fellman et al. 2010). However, warming extends the growing season, improving the potential for gardening and agriculture (GCRP 2014 citing Markon et al. 2012 and Weller 2005).

Fishing is the third largest industry in Alaska (GCRP 2014 citing Leask et al. 2001). Ocean acidification, warming ocean temperatures, melting sea ice, and other environmental changes can shift the abundance and location of fish (GCRP 2014 citing Allison et al. 2011, Cooley and Doney 2009, and Gaines et al. 2003). Recent changes have already resulted in near-surface fish species expanding their ranges northward (GCRP 2014 citing NRC 2011) and the invasion of non-native species to occur more rapidly (GCRP 2014 citing Markon et al. 2012 and Ruiz et al. 2000).

Although warming waters may enable some species to move northward into areas that had previously been uninhabitable due to sea ice (GCRP 2014 citing Loeng et al. 2005), cold bottom-water temperatures along the Alaskan continental shelf could limit this migration (GCRP 2014 citing Sigler et al. 2011). Additionally, warmer temperatures may affect fish species by reducing the abundance of species in their current geographic ranges (GCRP 2014 citing Mueter et al. 2011), threatening their health and survival (GCRP 2014 citing Farley et al. 2005), and increasing the frequency of early northward migration (GCRP 2014 citing Mundy and Evenson 2011). Change in the species mix, location, and timing of critical events introduce a new set of complications for fishery management and may cause the current fishing practices to be unsustainable (GCRP 2014 citing Mundy and Evenson 2011 and Hunt et al. 2011).

5.5.3.7.4 Terrestrial and Freshwater Ecosystems

Sea ice provides erosion control and protects coastal resources. Due to a decline in late-summer ice along the coast, storms have produced larger waves that cause more coastal erosion (GCRP 2014 citing Markon et al. 2012). Coastal bluffs, which had been previously “cemented” by ice-rich permafrost, are beginning to thaw and expose land that is susceptible to erosion (GCRP 2014 citing Overeem et al. 2011). There are several coastal communities where infrastructures and services have been affected by erosion, and a few communities have voted on community relocation or have already begun building infrastructure in a new location (Maldonado et al. 2013 and Bronen and Chapin 2013). *See* Section 5.5.2.2.

Permafrost thaw, greater rates of evaporation, and an increase in the accumulation of organic matter in soil due to a longer season for plant growth have decreased the area of lakes, on average, in the southern two-thirds of the state over the past 50 years (GCRP 2014 citing Klein et al. 2005, Roach et al. 2011, and Rover et al. 2012). However, the size of lakes in some locations is increasing as depressions at lake margins created by permafrost thaw are filled by melt water (GCRP 2014 citing Roach et al. 2011). These trends in permafrost thaw are projected to continue (GCRP 2014 citing Avis et al. 2011). Drying of lakes and wetlands could affect waterfowl nationally, because Alaska accounts for 81 percent of the National Wildlife Refuge system and provides critical breeding habitat for millions of migratory birds (GCRP 2014 citing CCSP 2008b).

5.5.3.7.5 Ocean Systems, Coastal, and Low-Lying Areas

Sea ice provides erosion control and protects coastal resources. Due to a decline in late-summer ice along the coast, storms have produced larger waves that cause more coastal erosion (GCRP 2014 citing Markon et al. 2012). Coastal bluffs, which had been previously “cemented” by ice-rich permafrost, are beginning to thaw and expose land that is susceptible to erosion (GCRP 2014 citing Overeem et al. 2011). There are several coastal communities where infrastructures and services have been affected by erosion, and a few communities have voted on community relocation or have already begun building infrastructure in a new location (Maldonado et al. 2013, Bronen and Chapin 2013). *See* Section 5.5.2.3.

Globally, the absorption of human-produced CO_2 has caused ocean waters to become 30 percent more acidic. The North Pacific Ocean is particularly susceptible to this phenomenon (GCRP 2014 citing NOAA 2010), because cooler water absorbs CO_2 more readily than warmer water (GCRP 2014 citing NOAA 2010 and Steinacher et al. 2009) and melting sea ice causes the waters to have a lower salt content, which also allows for greater CO_2 absorption (GCRP 2014 citing Yamamoto-Kawai et al. 2009). Increased acidity could have far-reaching impacts on the marine food web. Higher acidity reduces the capacity of key plankton and shelled organisms to produce and maintain shells and hard parts. This reduces the amount of food available for larger fish species that contribute to the commercial and subsistence fisheries (GCRP 2014 citing Cooley and Doney 2009 and Sambrotto et al. 2008).

The rate of erosion along Alaska's northeastern coastline has doubled over the past 50 years as a result of melting sea ice, increasing summer sea surface temperatures, rising sea level, thawing coastal permafrost, and increases in storminess and waves (Jones et al. 2009). Most of Alaska's more than 200 native villages are experiencing coastal erosion and flooding, resulting in millions of dollars in property damage and threats to lives and property (GAO 2009). Since 2003, federal, state, and village officials have identified 31 villages facing imminent danger (USACE 2009), and 12 of these have decided to relocate. Health and sanitation concerns are also increased as thawing permafrost results in deteriorating water and sewage systems (GCRP 2014 citing Alessa et al. 2008 and Brubaker et al. 2011b).

5.5.3.7.6 Urban Areas and Rural Areas

Alaska is unique in the United States in that approximately 80 percent of the land has permafrost (i.e., frozen ground that restricts water drainage) (GCRP 2014 citing Jorgenson et al. 2008). Permafrost thawing can cause damage to public infrastructure, such as disrupting water supplies and sewage systems (GCRP 2014 citing Alessa et al. 2008, Jones et al. 2009, and White et al. 2007), as well as roads, bridges, buildings, and airstrips (Karvetski et al. 2011 and Nelson et al. 2003). It is estimated that uneven sinking of the ground as a result of permafrost thaw will cost an additional $3.6 to $6.1 billion (10 to 20 percent) to maintain public infrastructure (GCRP 2014 citing Larsen et al. 2008). Additionally, permafrost vulnerability has decreased the period during which oil and gas exploration is permitted to about half the time permitted in the 1970s (GCRP 2014 citing Hinzman et al. 2005).

5.5.3.7.7 Human Security

As sea ice melts, the Arctic Ocean is becoming more accessible for marine traffic. Trans-Arctic shipping, oil and gas exploration, and tourism will have the capacity to expand with reduced ice extent (GCRP 2014 citing Smith and Stephenson 2013). Increased marine traffic could introduce or expand the risk for oil spills, maritime-related accidents, security challenges, international disputes, and traffic between the Pacific and Atlantic Oceans (GCRP 2014 citing Markon et al. 2012).

5.5.3.8 Islands (Hawaii and U.S. Affiliated Pacific Islands)[78]

This U.S. Pacific Islands include Hawaii, Federated States of Micronesia, Republic of the Marshall Islands, Republic of Palau, Territory of American Samoa, Territory of Guam, and Commonwealth of the Northern Mariana Islands. The region consists of more than 2,000 islands that span millions of square miles out into the ocean. These small islands are particularly vulnerable to climate change impacts, which will exacerbate current threats that islands are already facing: limitations of freshwater resources, frequency and intensity of tropical storms, ocean acidification, increasing ocean and ambient air temperatures, coastal erosion, sea-level rise, and threats to human security. These impacts have major implications for the islands' economies, communities, cultures, and aquatic and terrestrial ecosystems (GCRP 2014). Specifically, freshwater resources; ecosystems; agriculture and fisheries; and human security will be at risk.

5.5.3.8.1 Observed and Projected Changes in Exposure

Rising temperatures have been observed on U.S. tropical islands in recent decades and are projected to continue increasing (EPA 2009, GCRP 2014 citing Christensen et al. 2007 and IPCC 2007a). In a study using AOGCMs, projections were made over ocean surfaces, which were downscaled to predict

[78] Note that the Caribbean Islands, including Puerto Rico and the U.S. Virgin Islands, are covered with the Southeast region in this report.

temperatures over the land of islands since the AOGCM did not have a sufficiently fine resolution to capture the islands. In these projections, surface air temperatures increase 1.0 to 2.5°F by 2035 in Hawaii and the Central North Pacific (CNP) relative to 1971 to 2000 baseline (GCRP 2014 citing Christensen et al. 2007 and IPCC 2007a). In another study using a higher (A2) emissions scenario the Western North Pacific (WNP) is projected to have increasing surface air temperatures of 2.0 to 2.3°F by 2030 and 4.9 to 9.2°F by 2090 (GCRP 2014 citing Australian Bureau of Meteorology and CSIRO 2011). In the Central South Pacific (CSP), projected increases are to 1.1 to 1.3°F by 2030 and 2.5 to 4.9°F by 2090 under a higher (A2) emissions scenario, relative to 1971 to 2000 (GCRP 2014 citing Australian Bureau of Meteorology and CSIRO 2011). In Hawaii, high-elevation alpine ecosystems are already showing warmer temperatures that are projected to increase at a faster rate than lower elevation areas (GCRP 2014 citing Giambelluca et al. 2008 and Cao et al.2007). Sea surface temperatures are projected to increase as well. Under a lower (B1) emissions scenario, sea surface temperatures are projected to rise by 1.1°F by 2030, 1.8°F by 2055, and 2.5°F by 2090. Under a higher (A2) emissions scenario, sea surface temperatures could rise by 1.7°F by 2030, 2.3°F by 2055, and 4.7°F by 2090 compared to 1990 levels (GCRP 2014 citing Australian Bureau of Meteorology and CSIRO 2011).

While cyclical climate patterns such as El-Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) cause quite a bit of variability, thereby causing challenges in producing long-term precipitation trends, studies have identified regional precipitation trends within the U.S. Pacific Islands. For Hawaii and the eastern-most islands in the WNP, precipitation has been trending downward during the past century (Keener 2013). The eastern-most islands, such as the islands in the Micronesia region, have been observed to have 15 percent annual rainfall decline, yet the projected change in average annual precipitation over the period 2071 to 2099 under a higher emissions scenario that assumes continued increases in emissions (RCP 8.5) shows a projected increase in rainfall from 10 to 20 percent (GCRP 2014 citing NOAA 2012). In the western-most islands, however, overall trends have been slightly upward in the WNP. American Samoa has no significant trends, but this is based on very limited available data (GCRP 2014 citing Ganachaud et al. 2011).

Precipitation projections for this region do not suggest a spatially uniform change. For Hawaii, precipitation may reduce by 5 to 10 percent during the wet season and increase by 5 percent during the dry season by the end of the century, based on projections from statistically downscaled climate data (GCRP 2014 citing Timm and Diaz 2009). In this study, the linear downscaling was applied to a projection of the IPCC AR4 climate scenario for Hawaiian rainfall, relative to the 1970 to 2000 time period (Timm and Diaz 2009). In Micronesia, precipitation is projected to increase by the end of the century, while in Hawaii, the projections show decreasing precipitation in the northwestern islands and no change to a slight increase on the main islands. Precipitation projections, however, are less certain than those for temperature and have lower confidence in the anticipated findings (Keener et al. 2013).

With regard to sea-level rise, the global average has risen about 8 inches in the past century, with satellite observations indicating recent acceleration in the rate of se-level rise in the past 2 decades (GCRP 2014 citing Nerem et al. 2010). The IPCC AR5 also indicates that it is "*virtually certain*" that the global mean rates have accelerated in recent years and are projected to increase to the year 2100 (IPCC 2014b). Sea level of the Pacific is expected to rise at the global average rate with some regional variability due to changes in wind patterns, ocean circulation, storage in lakes and reservoirs, and melting glaciers (GCRP 2014 citing Stammer et al. 2013 and Seneviratne et al. 2012). For instance, regional sea level trends have demonstrated higher rates of rising in the western tropical Pacific than the global rates due to natural climate variability and changing wind patterns (GCRP 2014 citing Merrifield 2011). The U.S. Pacific Islands experience extreme sea level events when high tides are combined with other phenomena that affect water levels such as storms, ENSO, and other variations

(GCRP 2014 citing Merrifield 2011, Stammer et al. 2013, and Becker et al. 2012). Table 5.5.3-8 summarizes observed and projected trends in key environmental variables and affected resources.

Table 5.5.3-8. Observed and Projected Trends in Environmental Variables for the Islands

Environmental Variable	Observed Trend	Projected Trend	Affected Resource
Temperature	Increasing temperatures in annual mean air and sea surface temperatures; faster rising rates in higher elevation areas in Hawaii.	Increasing temperatures in the ambient air in CNP, WNP, and CSP Islands with increasing rates in higher elevation areas in Hawaii; and increasing mean sea surface temperatures.	▪ Terrestrial and freshwater ecosystems ▪ Ocean systems, coastal, and low-lying areas
Precipitation	Decreasing precipitation in Hawaii and eastern WNP islands, increasing precipitation in the western WNP islands.	Increases in annual precipitation in Micronesia and main Hawaiian islands and reductions in northwestern Hawaiian islands by the end of the century.	▪ Freshwater resources ▪ Ocean systems, coastal, and low-lying areas ▪ Food, fiber, and forest products ▪ Human security
Sea level	Rising, with rates observed as continuing to accelerate.	Observed increasing rates of sea-level rise, particularly in the western tropical Pacific.	▪ Freshwater resources ▪ Ocean systems, coastal, and low-lying areas ▪ Food, fiber, and forest products ▪ Human security

Notes:

Sources: EPA 2009; Keener et al. 2013; IPCC 2014b; GCRP 2014 citing Christensen et al. 2007, IPCC 2007a, Australian Bureau of Meteorology and CSIRO 2011, Timm and Diaz 2009, Nerem et al. 2010, and Merrifield 2011.

5.5.3.8.2 Freshwater Resources

The extent to which freshwater resources will be affected by climate change will vary for islands based on regional precipitation, ENSO events, storms, and climate variability, though generally, freshwater supplies are already constrained on islands and will continue to decline in availability (GCRP 2014 citing Oki 2004). In general, with temperature rising and precipitation decreasing on most islands, the availability of freshwater resources will be increasingly limited. Many small islands are already challenged with limited freshwater supply since highly volcanic and granitic islands, as well as islands with porous limestone, have limited storage capacity for precipitation (IPCC 2014c). Low-lying and smaller islands are also challenged with more limited availability of potable water sources, limited agricultural resources, geographic isolation, and increasing saltwater intrusion with sea-level rise and storms (GCRP 2014 citing Barnett and Adger 2003 and IPCC 2007b). Flooding from extreme events could also increase contamination risks to freshwater supplies from agriculture and sewage (EPA 2009). These trends on the U.S. Pacific Islands along with the geographic isolation and rising sea levels will stress islands' ecosystems, public health, agriculture, and communities (EPA 2009, GCRP 2014 citing Storlazzi et al. 2011).

5.5.3.8.3 Terrestrial and Freshwater Ecosystems

The U.S. Pacific Islands have many native flora and fauna species that are endemic to these small, biodiverse, and isolated terrestrial and freshwater ecosystems. Climate change impacts threaten the distribution, abundance, and overall existence of native island species with the combination of increasing temperatures, decreasing precipitation, and geographic isolation. Populations of terrestrial species are expected to migrate to higher elevations in response to rising temperatures (IPCC 2014c, GCRP 2014 citing Benning 2002). Survival of native species will also depend on the level of fragmentation of ecosystems, disturbances from extreme weather, the availability of higher elevation habitats, the pervasiveness of invasive species, and the survival of keystone species[79] (GCRP 2014 citing Bradley 2010). Some Hawaiian tree species have already experienced stresses from drought and heat, causing dramatic reductions in endemic species' population in the past 20 years (GCRP 2014 citing Krushelnycky et al. 2013). Decreasing precipitation and increasing temperature will also threaten freshwater ecosystems and aquatic species due to the resulting reductions of freshwater habitats. Survival of many freshwater invertebrates and fish is also vulnerable to changes in streamflow and oceanic conditions from climate change because their reproduction cycle tends to depend on seasonal returns to inland and oceanic larval phases (GCRP 2014 citing Keith 2003).

5.5.3.8.4 Ocean Systems, Coastal, and Low-lying Areas

The future existence of coral reefs is seriously threatened by climate change impacts. Improved data and satellite observations provide ample evidence that sea-surface temperatures have already increased in the region and will continue to increase under B1 and A2 emissions scenarios (GCRP citing the Australian Bureau of Meteorology and CSIRO 2011). Ocean warming has contributed to the spread of coral disease outbreaks and coral bleaching (GCRP 2014 citing Bruno 2007). There are also projections under the A1B scenario that increasing levels of CO_2, from 380 ppm in 2005 to 450 ppm in 2030, and 500 ppm in 2050, will decrease the regional ocean pH from 3.5 in 2005 to 3.25 by 2030 and 3.0 by 2050. This decreasing ocean pH is reflective of ocean acidification, which has increased about 30 percent in recent decades and is projected to increase from 37 to 50 percent from present levels by 2100 (GCRP 2014 citing Feely et al. 2009).There is no long-term recovery for acidification and bleaching, and of all coral reefs, 90 percent are projected to suffer severe bleaching by 2055 under the IPCC AR5 new Representative Concentration Pathway experiments (Hooidonk et al. 2014). In the absence of GHG mitigation, coral reefs in Hawaii may decline from the current coral cover of 38 percent to 5 percent by 2050, with additional loss after 2050 (EPA 2015g). By 2100, Hawaii is projected to lose 98 percent of current shallow-water coral (EPA 2015g).

At least three mass bleaching episodes have been observed in Hawaii in the past decade, while other incidences have been observed in Micronesia and American Samoa (GCRP 2014 citing Jokiel and Brown 2004 and Fenner et al. 2008). Ocean acidification will also lead to the degradation of calcium bi-carbonate, which is the building block of coral; increased mortality of Crutose coralline algae, which is also critical to the survival of coral; and increased fragility in surviving reefs (GCRP 2014 citing Kline et al. 2012 and Diaz-Pulido et al. 2012).

In a higher (A2) emissions scenario, continued loss of coral cover and coral reef habitat will result in extensive losses of reef species and fish (GCRP 2014 citing Pratchett 2011). In a lower (B1) emissions scenario, reefs are still projected to lose almost half of the associated species (GCRP 2014 citing Cesar

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[79] A species with a disproportionately large impact within the surrounding ecosystem due to its ability to maintain biodiversity by either controlling the population or by contributing as a major food source (Encyclopedia Britannica, Inc. 2014).

and Van Beukering 2004). The ocean's uptake of CO_2 has also been found to change critical survival behaviors in fish, thus threatening to alter the patterns and characteristics of surviving reef fish (Munday et al. 2014). These threats have serious implications for the communities and species dependent on reef ecosystems and their role in the food web. Coral reefs also account for about $385 million in goods and services annually for Hawaii alone, demonstrating that damage to the reefs will directly affect the island communities' productivity and economy (GCRP 2014 citing Caser and Beukering 2004). Damage to the coral reefs will also result in extensive reductions in population size and diversity of reef fishes, which will have unquantifiable detrimental impacts on the local environments, tourism, and sustenance (GCRP 2014 citing Aeby et al. 2009).

In addition to providing habitat to a host of marine species, coral reefs also dissipate wave energy, thereby reducing coastal impacts of erosion and storm surges. With the "*high confidence"* that there will be more frequent and extreme oceanic storm events, depletion of the coral reefs surrounding the U.S. Pacific Islands will result in increased impacts from coastal erosion, storms, ENSO events, and sea-level rise (IPCC 2014b).

5.5.3.8.5 Food, Fiber, and Forest Products

Climate change is projected to affect fisheries and agriculture, which are critical to the livelihoods of island communities. In a higher (A2) emissions scenario, the catch of highly profitable fish are projected to decline; the bigeye catch tuna, for example, is projected to decline by 27 percent from 2000 levels by 2100 (GCRP 2014 citing Sussman et al. 2008). Agriculture productivity is also at risk from freshwater limitations, rising temperatures, and rising sea levels. In Micronesia, for instance, a staple crop, Taro, is highly vulnerable to saltwater intrusion. If the brackish water inundates the swamp where the Taro is grown, it will require about 2 to 3 years of precipitation to flush out the brackish water before the next harvest planting can begin (GCRP 2014).

Low-lying and smaller islands will be more vulnerable to decreases in agricultural productivity due to the greater risk of increasing groundwater salinity from intrusion and flooding (GCRP 2014 citing IPCC 2007b). Low-lying areas are also more vulnerable to major coastal alterations from sea-level rise. For example, based on extrapolations of mangrove resilience relative to sea-level rise in American Samoa, 10 to 20 percent of the regions' mangrove area will be lost over the next century due to sea-level rise, which would further reduce the nursery and feeding grounds for a host of species, shoreline protection, and water filtration (GCRP 2014 citing Gilman et al. 2008).

5.5.3.8.6 Human Security

Climate change could affect nearly every aspect of life for the residents of the U.S. Pacific Islands. While island size is in jeopardy from sea-level rise and increasing coastal erosion, inland infrastructure is also threatened by increased wave heights, flooding, and extreme events. Airports and road networks are particularly vulnerable to climate change impacts, as they are typically located in the low-lying portions of islands (GCRP 2014 citing IPCC 2007b). Damage to these transportation systems would be extremely detrimental to island communities, as the geographic isolation of islands tends to lead to great dependency on importation for food, fuel, and other goods (GCRP 2014 citing Lewis 2012). Sea-level rise, extreme storm events, and flooding are also expected to overwhelm island sewage systems, destroy coastal artifacts and structures, impede cultural practices, and threaten the existence of traditional foods (GCRP 2014 citing Henry and Jeffrey 2008 and Codiga and Wager 2011). Depletion of the coral reefs, terrestrial environments, freshwater resources, infrastructure, and local economies could ultimately threaten the existence of U.S. Pacific Island communities and could lead inhabitants of the islands to consider emigration. This could lead to a slew of new challenges faced by the migrants and the receiving countries including employment, resources, placement, and governing of possible masses of island migrants (GCRP 2014).

5.5.3.9 Indigenous Peoples

This section focuses on the climate impacts anticipated to affect the indigenous peoples. Key climate change vulnerabilities for indigenous peoples include traditional knowledge, traditional food sources, water quality and quantity, sea ice, permafrost, and forced relocation. Indigenous peoples are likely to be disproportionally affected by climate change impacts since their diets, culture, and infrastructure are closely tied to local resources. Furthermore, many tribes lack the financial resources to adequately adapt and respond to climate change—as exemplified by a 28.4 percent poverty rate of native peoples, compared to 15.3 percent poverty rate nationally (GCRP 2014 citing Freeman and Fox 2005; Macartney et al. 2013).

5.5.3.9.1 Observed and Projected Changes in Exposure

Many Native American reservations are located in the Northwest, Southwest, Great Plains, and Alaska (GCRP 2014 citing Norris et al. 2012). Due to the geographic diversity, the climate change impacts and trends are discussed in the respective regional chapters. The climate stressors of most relevancy for this population group are increased temperatures, changes in precipitation patterns, and sea-level rise. These environmental variables have observed and projected impacts on traditional knowledge; food, fiber, and forest products; freshwater resources, rural areas, human health, and human security. In this section, traditional knowledge is treated as a unique resource to indigenous peoples.

5.5.3.9.2 Impacts of Climate Change on Traditional Knowledge

Working Group II of the Intergovernmental Panel on Climate Change Fourth Assessment Report has identified traditional knowledge as an important component to understanding climatic changes and developing adaptation strategies (GCRP 2014 citing IPCC 2007b). Those living off of the land have been longstanding climate change witnesses, and are at times best equipped to report shifts in local ecosystems. A tribe located on the northern Great Plains, for example, has tracked climatic changes through yearly pictographs of buffalo hides (GCRP 2014 citing Nickels et al. 2005). In some cases, scientists have recognized the importance of traditional knowledge in documenting climate change, and have started to work with tribal leaders. On the Navajo Reservation, scientists and the Navajo elders worked together to observe meteorological and hydrological changes (GCRP 2014 citing Redsteer et al. 2011). The EPA Region 10 Tribal Leaders Summit 2010 Action Plan states that the federal agencies in collaboration with tribes in Region 10 "will sponsor a workshop to explore the connections between indigenous knowledge, citizen science, and western science" (Vinyeta and Lynn 2013 citing EPA 2010).

According to GCRP 2014, "many indigenous resource managers believe their cultures already possess sufficient knowledge to respond to climate change" (GCRP 2014 citing First Stewards 2012, Merideth et al. 1998). Traditional knowledge is passed down through cultural elements, such as song, dance, and storytelling. However, as traditional ways of life are becoming increasingly threatened by climate change, the tribal leaders' knowledge is declining with each new generation (GCRP 2014).

5.5.3.9.3 Food, Fiber, and Forestry

Climate change is threatening indigenous peoples' traditional food sources, as agricultural seasons are shortening, migration patterns are shifting, and arctic hunting grounds are melting. Shifts from traditional diets have led to health problems, food insecurity, reliance on costly non-traditional foods, and loss of culture (GCRP 2014 citing Cochran et al. 2013, Lynn et al. 2013, U.S. Commission on Civil Rights 2003).

Some climate change impacts on traditional food sources, such as species loss and shifts in species range, have already been observed (GCRP 2014 citing Cochran et al. 2013, Coastal Louisiana Tribal Communities 2012, Rose 2010, Swinomish Indian Tribal Community 2010). For example, warmer winters in Maine are lengthening the tick season, which causes harm to the moose population (GCRP 2014 citing Daigle and Putnam 2009). Additionally, wild rice has been increasingly difficult to grow within historical ranges in the Great Lakes region due to changes in temperature and water levels (GCRP 2014). Range shifts in forest foods, such as berries, have also been observed by the Wabanaki tribe in the northeast (GCRP 2014). Similarly, according to GCRP 2014, shifts in growing areas have caused some medicinal foods to become sparse (GCRP 2014 citing Lynn et al. 2013 and Riley et al. 2012). The Yakama Nation, comprised of 14 tribes, has already begun to create water management plans, anticipating the impacts of limited water resources on their traditional, salmon-heavy diets (Montag et al. 2014).

Furthermore, climate change may affect cultural traditions tied to food. For example, certain Alaskan Natives have cultural ties with animals, such as seals and caribou; these species will experience changes to their habitat as a result of climate change (GCRP 2014).

5.5.3.9.4 Freshwater Resources

Climate change impacts—such as droughts and changes in precipitation—are threating indigenous peoples' access to sufficient quantities of quality water. This is made worse by poor government policies and regulations. For example, extractive industries near native lands are decreasing water supplies and contaminating water (e.g., an oil spill upstream from a reservation in North Dakota in 2013) (GCRP 2014).

Additionally, many indigenous cultures lack the financial resources necessary to maintain basic water infrastructure (GCRP 2014 citing Ferguson et al. 2011). As a result, several reservations have water infrastructure that is in need of repair or lacking entirely. For example, 30 percent of the Navajo Nation do not have access to municipal water systems and fetch water from local water resources (GCRP 2014 citing Navajo Nation Department of Water Resources 2011 and Redsteer et al. 2011).

Other tribes along the coasts are facing ocean acidification and shoreline erosion. The Shinnecock Indian Nation in Long Island, for example, has experienced poor shellfish survival rates and loss of trees along the shoreline. The Shinnecock Indian Nation, similar to other coastal tribes, is also particularly vulnerable to flooding and storm surges (Shinnecock Indian Nation 2013).

5.5.3.9.5 Rural Communities

Climate change is causing increasing temperatures and melting the sea ice. Information from NASA Earth Observatory 2012 revealed that from 1979 to 2000, the average area of sea ice in the Arctic Ocean was 2.59 million square miles. By the end of the summer 2012, the sea ice area had been reduced to 1.32 million square miles (GCRP 2014 citing NASA Earth Observatory 2012). The sea ice is expected to continue to melt as temperatures rise (GCRP 2014 citing Pungowiyi 2009, Hinzman et al. 2005, Laidler et al. 2009, and Pungowiyi 2002). Declining sea ice directly affects those native Alaskan populations who live on the ice. The impacts include loss of culture as sacred areas become unsafe or unusable; food insecurity as animals migrate beyond hunting ranges; increased risk for hunting, fishing, or herding as sea ice thins; increased risk from severe storms as protection from coastal sea ice is eroded; and forced relocation of entire tribes as areas become inhabitable (GCRP 2014 citing Cochran et al. 2013, Brubaker et al. 2011a, Pungowiyi 2002, Parkinson 2010, and NASA Earth Observatory 2012).

5.5.3.9.6 Human Health

Climate change is causing increasing temperatures, thawing permafrost—otherwise known as *permanently frozen soil*. When permafrost melts, the land above it sinks and changes shape. Sinking land damages buildings, roads, water pipes, and leads to land erosion. Permafrost thaw can also lead to increased flooding and health issues (GCRP 2014). For example, many Alaskan Native communities depend on permafrost to store frozen foods. Modern electric alternatives are expensive (GCRP 2014). Decline in proper refrigeration is affecting health as food becomes contaminated, or tribes are otherwise more dependent on less healthy, store-bought foods (GCRP 2014 citing Cochran et al. 2013, Parkinson and Evengård 2009, and Brubaker et al. 2009).

Land erosion caused by permafrost thaw results in "loss of clean water for drinking and hygiene, saltwater intrusion, and sewage contamination" that could cause health issues, such as "respiratory and gastrointestinal infections, pneumonia, and skin infections" (GCRP 2014 citing Cochran et al. 2013, Parkinson 2010, McClintock 2009, and Parkinson and Evengård 2009).

5.5.3.9.7 Human Security

Climate change impacts, such as sea-level rise, increase in severe storms, drought, and shifts in diseases, are forcing many native communities to consider relocation. Over 30 Alaskan villages are in need of relocation, or are already in the process of moving (GCRP 2014 citing Cochran et al. 2013 and Bender et al. 2011). Tribal communities in Louisiana are facing inhabitable lands due to rising sea levels, saltwater intrusion, and pollution from nearby extractive industries (GCRP 2014 citing Maldonado et al. 2013 and Coastal Louisiana Tribal Communities 2012). "The Quileute tribe in northern Washington is responding to increased winter storms and flooding connected with increased precipitation by relocating some of their village homes and buildings to higher ground within 772 acres of Olympic National Park that has been transferred to them; the Hoh tribe is also looking at similar options for relocation" (GCRP 2014 citing Papiez 2009, Walker 2012, and Quileute Newsletter 2011). For native Pacific Island communities, rising sea levels are forcing them to consider relocation (GCRP 2014 citing Souzaand Tanimoto 2012, IPCC 2007a).

"Currently, the [United States] lacks an institutional framework to relocate entire communities. National, state, local, and tribal government agencies lack the legal authority and technical, organizational, and financial capacity to implement relocation processes for communities forcibly displaced by climate change" (GCRP 2014 citing Maldonado et al. 2013 and Whyte 2013). For the Newtok—a village in Alaska—climate change has affected their infrastructure and basic necessities (GCRP 2014 citing Maldonado et al. 2013 and Cochran et al. 2013). Their progress toward relocation has been limited by federal statutes and regulations. Additional barriers toward relocation for any Alaskan Native villages, such as the Newtok, include an absence of legal authority and governance structure (GCRP 2014 citing Maldonado et al. 2013, Bronen 2011, and Alaska Department of Commerce and Community Economic Development 2012).

For those tribes who have already relocated, the displacement is causing loss of identity and culture, increased health risks, and is further exacerbating poverty (GCRP 2014).

5.6 Non-Climate Cumulative Impacts of Carbon Dioxide

This section describes the non-climate cumulative impacts of CO_2, including ocean acidification (5.6.2.1) and effects on plant and soil microorganism growth and diversity (5.6.2.2).

5.6.1 Affected Environment

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); 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, the concentration of CO_2 in the atmosphere affects soil microorganisms. Recent research has underscored the importance of feedbacks between the aboveground and belowground components of terrestrial ecosystems 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, "explain 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. As with the climatic effects of CO_2, the changes in non-climate impacts associated with the action alternatives are difficult to assess quantitatively because the incremental changes in atmospheric CO_2 associated with the action alternatives translate to very small changes in ocean acidification and CO_2 fertilization. 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 Sections 5.6.2.1 and 5.6.2.2.

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, thus, makes seawater more acidic (IPCC 2007a, Doney et al. 2009a, 2000b, 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 less available 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 carbonate ion concentration (see reviews by Doney et al. 2009a, Doney et al. 2009b, EPA 2009, Fabry et al. 2008, IPCC 2007a, Guinotte and Fabry 2008, The Royal Society 2005, NRC 2010, and SCBD 2009).

The findings on ocean acidification presented in this section are drawn primarily from recently released reports including the *IPCC WG1 AR5* (IPCC 2013a, IPCC 2013b) and the GCRP *National Climate Assessment (NCA) Report* (GCRP 2014).

These key findings include information on the oceans' role in absorbing CO_2 (and heat), the resulting increase in ocean acidity, and the impacts of ocean acidification on marine life.

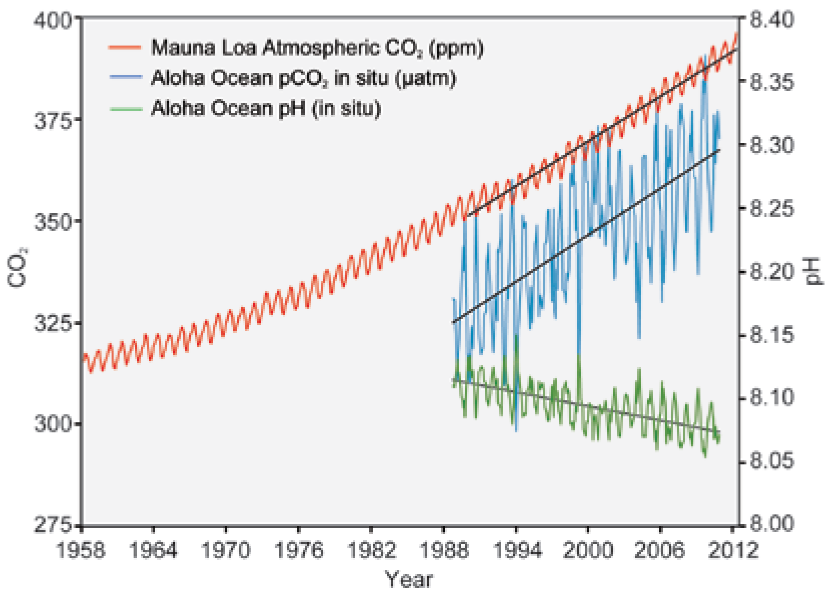
5.6.2.1.1 Increases in Ocean Acidity Resulting From CO_2 Emissions

The SPM reports that atmospheric concentrations of CO_2, CH_4, and NO_x have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40 percent since preindustrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. Both the SPM and NCA report that the ocean has absorbed about 30 percent of the emitted anthropogenic CO_2, causing ocean acidification (*see* Figure 5.6.2-1). The SPM also reports that the pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (*high confidence*), corresponding to a 26 percent increase in hydrogen ion concentration,[80] and that further uptake of carbon by the ocean will increase ocean acidification. Under all four (RCPs) scenarios, ocean

[80] Ocean acidification is quantified by decreases in pH; pH is a measure of acidity using a logarithmic scale: a pH decrease of 1 unit corresponds to a 10-fold increase in hydrogen ion concentration, or acidity.

uptake of anthropogenic CO_2 would continue through to 2100, with higher uptake for higher concentration pathways (*very high confidence*).[81]

Figure 5.6.2-1. As Oceans Absorb CO_2 They Become More Acidic[a,b]



[a] Source: GCRP 2014 modified from Feely et al. 2009.

[b] The correlation between rising levels of CO_2 in the atmosphere (red) with rising CO_2 levels (blue) and falling pH in the ocean (green). As CO_2 accumulates in the ocean, the water becomes more acidic (the pH declines).

CO_2 = carbon dioxide; ppm = parts per million; pCO_2 = partial pressure of carbon dioxide; µatm = microatmospheres

The GCRP reports that projections indicate that in higher emissions pathways, such as SRES A2 or RCP 8.5, pH could be reduced from the current level of 8.1 to as low as 7.8 by the end of the century (GCRP 2014 citing Orr et al. 2005). Such large changes in ocean pH have probably not been experienced on the planet for the past 100 million years, and it is unclear whether and how quickly ocean life could adapt to such rapid acidification (GCRP 2014 citing Hönisch et al. 2012).

The SPM briefly notes that geoengineering methods proposed to deliberately alter the climate system to counter climate change (e.g., solar radiation management) may have the potential to substantially offset a global temperature rise (as well as modify the global water cycle), but they would not reduce ocean acidification (*see* also GCRP 2014).

5.6.2.1.2 Impacts of Ocean Acidification on Marine Life

The NCA reports that ocean waters are becoming warmer and more acidic, broadly affecting ocean circulation, chemistry, ecosystems, and marine life. More acidic waters inhibit the formation of shells, skeletons, and coral reefs. Warmer waters harm coral reefs and alter the distribution, abundance, and productivity of many marine species. The rising temperature and changing chemistry of ocean water combine with other stresses, such as overfishing and coastal and marine pollution, to alter marine-based

[81] Earth System Models project a global increase in ocean acidification for all RCP scenarios. The corresponding decrease in surface ocean pH by the end of 21st century is in the range18 of 0.06 to 0.07 for RCP2.6, 0.14 to 0.15 for RCP4.5, 0.20 to 0.21 for RCP6.0, and 0.30 to 0.32 for RCP8.5.

food production and harm fishing communities (GCRP 2014). There are already a number of corals proposed for listing or reclassification under the Endangered Species Act.[82]

The NCA also reports that ocean acidification is expected to affect ocean species to varying degrees. For example, some photosynthetic algae and seagrass species could benefit from higher CO_2 conditions in the ocean, as they require CO_2 to live, as do plants on land. On the other hand, studies have shown that a more acidic environment has dramatic negative effects on some calcifying species, including pteropods, oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton. When shelled species are at risk, the entire food web could also be at risk (GCRP 2014). As a likely result, there is a rapid growth in peer-reviewed publications describing how ocean acidification will impact ecosystems (GCRP 2014 citing Cooley et al. 2009 and Doney et al. 2009b), but to date, evidence is largely based on studies of calcification rather than growth, reproduction, and survival of organisms. For these latter effects, available evidence is from laboratory studies in low pH conditions, rather than in situ observations (GCRP 2014 citing Kroeker et al. 2013). Although studies are underway to expand understanding of ocean acidification on all aspects of organismal physiology, much remains to be learned (GCRP 2014).

That said, confidence is *very high* that CO_2 emissions to the atmosphere are causing ocean acidification, and *high* that this will alter marine ecosystems. The nature of those alterations is unclear, however, and predictions of most specific ecosystem changes have *low confidence* at present, but with *medium confidence* for coral reefs (GCRP 2014).

5.6.2.2 Plant Growth and Soil Microorganisms

Plants and soil microorganisms, both key players in terrestrial carbon storage, are predicted to have complex responses to climate-induced changes (GCRP 2014 citing Melillo et al. 2011, IPCC 2013b). For example, several studies have shown that increased CO_2 concentrations increase the growth rates of some plant species under conditions of sufficient water and nutrient availability (GCRP 2014, Rosenthal and Tomeo 2013). However, while increased growth rates do potentially increase carbon sequestration, they do not necessarily lead to increased plant production or yield (GCRP 2014). That is, while changes in temperature, CO_2 concentrations, and solar radiation could benefit plant growth rates, such rates will not necessarily translate to increased yield of grain, forage, fruit, or fiber (GCRP 2014). Reductions in solar radiation over the last 60 years (due to increased clouds and humidity) (GCRP 2014 citing Qian et al. 2007) are projected to continue (GCRP 2014 citing Pan et al. 2004) which can reduce high temperature and elevated CO_2 accelerated plant growth (GCRP 2014). Overall projections for crop production systems indicate that climate change effects over the next 25 years will be mixed (Walthall et al. 2012) although most predictions for climate change effects on crop yields by 2050 are negative (Nelson et al. 2014).

Similarly, the effects of climate change on soil microbial communities and their corresponding impacts on terrestrial carbon pools are complex and not well understood (Wieder et al. 2014). The soil microbial community and structure is comprised of numerous species (including bacteria and fungi) whose survival and growth rates are affected by temperature, moisture, nitrogen, phosphorus, soil type, extreme weather events, land management practices and the local plant community structure (GCRP 2014 citing Janssens et al. 2010, Knorr et al. 2005, and Melillo et al. 2011; Stockmann et al. 2013; Bardgett et al. 2013). Changes in these and other conditions can contribute to an increase or decrease in microbial growth which directly impact terrestrial carbon sequestration. For example, warmer soil

[82] *See* http://www.nmfs.noaa.gov/pr/species/invertebrates/corals.htm.

temperatures have been shown to increase organic-matter decomposition rates thus increasing CO_2 emissions from soils (GCRP 2014). However, increased decomposition in soil increases release of essential plant nutrients (reactive nitrogen and phosphorus) which can increase plant growth thus increasing carbon sequestration (GCRP 2014 citing Melillo et al. 2011). Microbial growth is also affected by available nitrogen, particularly in cold, wet environments, and human introduction of nitrogen (mostly through application of fertilizer) could increase the decomposition of organic matter, increasing the release of CO_2 (IPCC 2013). The current annual exchange in CO_2 between the atmosphere and terrestrial ecosystems is estimated to be 9 to 10 times greater than annual emissions produced from 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). Current models predict that warmer temperatures will result in overall losses of carbon sequestration in soils (Wieder et al. 2014) though there is debate over how accurately these models predict changes to soil microbial growth (Schimel 2013).

5.6.2.2.1 Effect of Elevated CO_2 Concentrations on Plant Growth

Bench- and field-scale experiments have shown that higher CO_2 concentrations have a fertilizing effect on plant growth (e.g., Long et al. 2006, Schimel et al. 2000) with considerable variability between regions (McGrath and Lobel 2013). Compared to current CO_2 conditions, free air enrichment experiments with 550 ppm CO_2 (the amount predicted to be present by approximately 2050) yielded a 10 to 25 percent increase in growth of unstressed C3 crops (e.g., wheat, soybeans, and rice) and up to a 10 percent increase in growth of C4 crops (e.g., maize) (EPA 2009).[83] In addition, an IPCC review and synthesis of field and chamber CO_2 enrichment studies found that:

- Plants show a large range of responses, with woody plants consistently showing net primary productivity increases of 23 to 25 percent (Norby et al. 2005), and grain crops showing much smaller increases (Ainsworth and Long 2005).
- Overall, approximately two-thirds of the experiments show positive responses to increased CO_2 concentrations (Ainsworth and Long 2005, Luo et al. 2004).

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 thus reducing plant nutrition. In one study, such fertilization of forage grasses for livestock increased their abundance but reduced their nutritional value, affecting livestock weight and performance (EPA 2009).

In addition to increases in growth rates for aboveground biomass, experiments have also shown that elevated CO_2 levels cause an increase in belowground net primary production and fine-root biomass (Madhu and Hatfield 2013; 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). Studies have shown that under elevated CO_2 conditions, roots become more numerous, longer, thicker, and faster-growing with many species also showing increased root length (Madhu and Hatfield 2013). For example, Jackson et al (2009) found that under elevated CO_2, roots showed 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. Despite these increases, studies show that agricultural management practices have a greater impact on root growth than rising CO_2 levels (Madhu and Hatfield 2013). Because CO_2 stimulated growth is commonly limited by nutrients or other factors (Dukes et al. 2009, Körner et al.

[83] C_3 and C_4 plants are differentiated by the manner through which they use CO_2 for photosynthesis, accounting for the differences in plant yield under similar ambient CO_2 conditions.

2005), the magnitude and effect of CO_2 fertilization on plant growth under environmental conditions is not yet clear (McGrath and Lobell 2013). Easterling et al. (IPCC 2007) present studies suggesting that the CO_2 fertilization effect might be lower than previously assumed, with growth increases 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 2009). McGrath and Lobell (2013) found that there is a strong regional effect on CO_2 induced yield increases likely due to regional differences in climate and the mixture of crops. Additionally, CO_2 fertilization only has a positive effect on plant growth over a limited range of concentrations. Studies show that any increase in CO_2 concentration above 5 percent is likely to adversely affect vegetation (EPA 2009) and concentrations of 20 percent and higher have been shown to cause phytotoxic[84] effects (EPA 2009).

5.6.2.2.2 Effect of Elevated CO_2 Concentrations on Soil Microorganisms

Elevated CO_2 concentrations can affect soil microbial growth rates. In one study, an increase in CO_2 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). However, 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 alters the concentration of CO_2 in soil pore spaces, which affects weathering of carbonates, silicates, and other soil minerals (Andrews and Schlesinger 2001, Jackson et al. 2009 citing Sposito 1989, Pendall et al. 2001, and Karberg et al. 2005).

The increase in microbial respiration associated with elevated CO_2 concentrations could thus diminish the carbon sequestration role of terrestrial ecosystems. Elevated CO_2 levels were also found to significantly alter microbial community structure and composition, which could have significant impacts on soil carbon and nitrogen dynamics (He et al. 2010). Additionally, up-regulation of many of the genes involved in C decomposition in these communities could further impact 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).

5.6.2.2.3 CO_2-Physiological Forcing

Elevated CO_2 concentrations have physiological impacts on plants, which can result in changes in both plant water utilization and local climate. A process referred to as "CO_2-physiological forcing" (Cao et al. 2010) occurs when increased CO_2 levels cause plant stomata (pores in plant leaves which allow for gas exchange of CO_2 and water vapor) to open less widely, resulting in decreased plant transpiration (Cao et al. 2010). Reduced stomata opening can result in a variety of effects. In terms of water utilization, reduced stomata opening increases water use efficiency in C3 and C4 plants, which can decrease canopy water use and increase soil moisture content, thus mitigating yield loss under drought conditions (McGrath and Lobel 2013 citing Ainsworth and Rogers 2007, Leakey 2009, Hunsaker et al. 2000, Conley et al. 2001, Leakey et al. 2006, Leakey et al. 2004, and Bernacchi et al. 2007). In terms of climate

[84] Phytotoxicity is an abnormal adverse reaction of plants.

change, reduction in canopy transpiration causes a decrease in evapotranspiration that triggers adjustments in water vapor, clouds, and surface radiative fluxes. These adjustments could ultimately drive macroclimatic 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 0.42 plus or minus 0.02°C (0.76 plus or minus 0.04°F) 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).

5.6.2.2.4 Ozone and Other Gases

Tropospheric ozone is mainly produced from NO_X, CO and VOCs (GCRP 2014). Ozone has a negative effect on plant growth and biomass accumulation while CO_2 and ammonia (NH_3) act synergistically to increase plant growth (GCRP 2014). Nitrogen deposition drives temperate forest carbon storage by increasing plant growth by slowing organic-matter decomposition (GCRP 2014 citing Janssens et al. 2010 and Knorr et al. 2005). Sulfur dioxide (SO_2) is expected to reduce plant growth through the leaching of soil nutrients and increasing of radiative forcing (GCRP 2014).

5.6.2.2.5 Higher Temperatures

Climate induced increases in temperature will have both positive and negative impacts on carbon storage in plants and soils. For example, higher temperatures increase decomposition rates thereby increasing CO_2 emissions from microbial respiration. However, increased decomposition rates also accelerate the release of reactive nitrogen (and phosphorus) from organic matter, which can spur additional plant growth (GCRP 2014 citing Melillo et al. 2011). Plant net primary productivity (NPP)[85] is affected by temperature, and the combined effects of ecosystem carbon storage will depend on the extent to which nutrients constrain both net primary productivity and decomposition, on the extent of warming, and on whether any simultaneous changes in water availability occur (GCRP 2014 citing Dijkstra et al. 2012, Schimel et al. 2001 and Wu et al. 2011).

Longer Growing Season

The frost-free season (and corresponding growing season) has been increasing since the 1980s with the largest increase occurring in the western United States. This change is affecting ecosystems and agriculture across the United States and is projected to continue to lengthen (GCRP 2014). A longer growing season provides a longer period of plant growth and productivity which can slow the increase in atmospheric CO_2 concentrations through increased biogenic uptake of CO_2 (GCRP 2014 citing Peñuelas et al. 2009). A 6 percent increase in global NPP, or the accumulation of 3.4 petagrams of carbon (PgC), was observed in satellite greenness on land from 1982 to 1999 (IPCC 2013b citing Nemani et al. 2003; IPCC 2013b). This trend was attributed to increased plant growth in high latitudes (IPCC 2013b). Increased NPP due to warming was partially offset by global soil respiration which also increased between 1989 and 2008, reducing the magnitude of the net land sink (IPCC 2013b citing Bond-Lamberty and Thomson 2010).

[85] The total amount of CO_2 stored by a plant through photosynthesis minus the amount released through respiration.

Overall, there is *high confidence* that climate change effects on crop production are evident in several regions of the world and negative trends are more common than positive ones (IPCC 2014b). There is *high confidence* that CO_2 has overall stimulatory effects on crop yields, and that elevated tropospheric ozone has negative effects on crop yields. Impacts to crop yields are difficult to predict due to non-linear interactions between CO_2, tropospheric ozone, mean and extreme temperatures, water, and nitrogen; there is *medium confidence* in the understanding of these interactions (IPCC 2014b). There is currently *high confidence* that biomass and soil carbon stocks are currently increasing, but are vulnerable to future loss to the atmosphere due to rising temperatures, drought and fire projected in the 21st century (IPCC 2014b).

CHAPTER 6 LIFE-CYCLE IMPACT ASSESSMENT OF VEHICLE ENERGY, MATERIALS, AND TECHNOLOGIES

6.1 Introduction

The International Organization for Standardization (ISO) defines a Life-Cycle Assessment (LCA) as the “compilation and evaluation of the input, output, and potential environmental impact of a product system throughout its life cycle” (ISO 2006). Like any product, a vehicle’s LCA impacts do not accrue exclusively during the time it spends in use (i.e., they are not limited to engine exhaust emissions and evaporative emissions). Each stage of a vehicle’s life cycle, including vehicle fuel production, contributes to GHG emissions, energy use, and other environmental impacts.

NHTSA recognizes that life-cycle considerations inform decisionmakers in this rulemaking. Air quality and climate impacts reported in Chapters 4 and 5 include upstream emissions resulting from the use, leakage, spillage, and evaporation of fuels during feedstock production (e.g., crude oil or natural gas [NG]); feedstock transportation (to refineries or processing plants); fuel refining and processing (into gasoline, diesel, dry NG, and NG liquids); and refined product transportation (from bulk terminals to retail outlets). These upstream emissions included in Chapters 4 and 5 account for less than 25 percent of total GHG emissions from HD vehicle fuel use and 7 to 96 percent of non-GHG emissions from HD vehicle fuel use, depending on the specific pollutant. Air quality and climate impacts reported in Chapters 4 and 5, however, include only emissions associated with the vehicle fuel life-cycle. Therefore, Chapters 4 and 5 do not include any estimated life-cycle impacts associated with HD vehicle materials or technologies themselves that might be applied to improve fuel efficiency, including emissions related to vehicle manufacturing.

A complete LCA of the impacts of this rulemaking, which is beyond the scope of this EIS, would require extensive information about many variables that are highly uncertain, including the future behavior of HD vehicle manufacturers in response to the Phase 2 standards, the specific design of multiple fuel efficiency technologies (and how they are manufactured, applied to vehicles, and disposed of after use), interactions between application of those technologies, and specific details on the variety of vehicle types, manufacturers, and uses expected in the future. HD vehicle standards are performance-based rather than technology-mandating. As a result, NHTSA does not know precisely how manufacturers will choose from a suite of available technologies to meet the Phase 2 standards. Instead, NHTSA is presenting a literature synthesis of existing credible scientific information relevant to evaluating the potential environmental impacts from some of the fuels, materials, and technologies that may be used to comply with the Final Action and alternatives.

This literature synthesis is presented in the following four sections:[1]

- The remainder of Section 6.1 provides background on applying LCA methods to HD vehicles.

[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. The impacts are included here to inform decisionmakers and the public about certain broader environmental implications of the rulemaking action.

- Section 6.2 examines LCA impacts associated with different HD vehicle fuels.
- Section 6.3 examines LCA impacts associated with HD vehicle materials and technologies.
- Section 6.4 presents conclusions from this literature synthesis.

This chapter does not attempt to provide a comprehensive review of all LCA studies related to HD vehicles, but rather it focuses on recent studies that provide more background on upstream emissions already incorporated in the analyses in Chapters 4 and 5, as well as the material and technology LCA impacts not reflected in the analyses in Chapters 4 and 5. The main purpose of this literature synthesis is to supplement quantitative analysis of alternatives reported in Chapters 4 and 5.

6.1.1 Overview of Life-Cycle Assessment in the Vehicle Context

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 production of virgin materials (e.g., ore, crude oil), 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. Manufacturing often consists of sub-stages, including material and part production and vehicle assembly. The use stage typically comprises two sub-stages: the driving sub-stage (e.g., fuel combustion) and maintenance (e.g., part repair or replacement). End-of-life management can include such steps as parts recovery, disassembly, shredding, recycling, and landfilling.

An LCA study can help determine whether certain materials and technologies save energy over the entire life cycle of vehicles, keeping other factors (e.g., miles traveled, tons of freight carried, vehicle life) equal. Changes in the material composition of vehicles could decrease the emissions potential of the use stage but increase that of the raw material extraction and manufacturing stages (Geyer 2008). On the other hand, because of the high proportion of total emissions during the use stage, the fuel-saving benefits realized during a vehicle's use due to improved fuel economy could very likely outweigh the additional energy investment associated with material changes (Cheah et al. 2009).

While LCA allows users to evaluate the environmental impacts of different vehicle technologies on an equal basis *within* a given study, LCAs nonetheless often 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, environmental impact categories to consider, and other factors that address the defined purpose of the study. Most studies in this literature synthesis evaluate different types of vehicles with different assumptions for vehicle 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 and material inputs. Others include impacts only from cradle to [factory] gate (i.e., from resource extraction through manufacturing and assembly, but excluding vehicle use and end of life). Most of the studies evaluate energy use and climate change impact measured by GHG emissions, but several also include 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 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 material can perform functions after its use in an HD vehicle. 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 limits the comparability of the results.

For some of the studies considered in this chapter, the authors used existing models to assess life-cycle emissions. Other studies included independent assessments of life-cycle implications using study-specific models developed from life-cycle inventory data sources such as the ecoinvent database.[3] The most commonly used model in the surveyed literature was GHGs, Regulated Emissions, and Energy Use in Transportation (GREET) model, a public-domain model developed at Argonne National Laboratory (ANL) that allows users to estimate life-cycle energy and emissions impacts on a full fuel-cycle and vehicle life-cycle basis (ANL 2014). ANL developed GREET in 1996 and has updated the model to reflect recent data, new fuel pathways, and vehicle technologies. GREET uses a process-based approach wherein the model calculates life-cycle results by modeling the various processes and technologies used to extract, refine, and distribute fuels, and to manufacture, use, and dispose of vehicles. The upstream emissions included in the air quality and climate impacts reported in Chapters 4 and 5 of this EIS are estimates based on information from GREET.

In addition, several studies used the Economic Input-Output LCA Model developed by Carnegie Mellon University's Green Design Institute (CMU GDI 2008). The model is not specific to fuel and vehicle LCA, but it can be used to estimate the energy and emissions impacts of components, materials, and industries involved in the vehicle component manufacturing supply chain. The Green Design Institute periodically updates the model to reflect new input-output data and impact characterization data and methods. The Economic Input-Output LCA Model assumes that GHG emissions are linked to economic flows through different sectors. Therefore, unlike GREET, the model is not process-based; it is most applicable to assessing impacts from an industry sector (e.g., vehicle manufacturing) rather than specific products (e.g., a specific vehicle make or model).

Some studies used the Mobile Source Emission Factor (MOBILE) model—which calculates gram-per-mile emissions of hydrocarbons, carbon monoxide, nitrogen oxides (NO_x), carbon dioxide (CO_2), particulate matter, and toxics from vehicles—to refine estimates of pollution from the use phase of vehicles. MOBILE is not a life-cycle model; rather, it focuses only on emissions from vehicles during the use phase. Data in MOBILE are based on emissions testing of vehicles and account for several factors, including changes in vehicle emissions standards, changes in vehicle populations and activity, and variation in local conditions, such as temperature, humidity, and fuel quality. MOBILE, which was developed and updated by the Environmental Protection Agency (EPA) from 1978 to 2010, has since been replaced by EPA's Motor Vehicle Emission Simulator (MOVES).

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[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).

[3] Life-cycle inventory data is information on the inputs, outputs, and potential environmental impacts of a product or process. The ecoinvent database, managed by the Swiss Centre for Life Cycle Inventories, is a large source of life-cycle inventory data on products and processes from different countries around the world, including the United States.

Because LCAs are highly sensitive to design and input assumptions, their results reflect variation in impacts. Despite study differences, based on the studies considered for this synthesis, it is clear that most energy is consumed and most GHGs are emitted during the vehicle use stage. Hakamada et al. (2007) estimate that this stage accounts for approximately 80 percent of the life-cycle vehicle GHG emissions in conventional internal combustion engine vehicles, which is consistent with the vehicle use share of GHG emissions reflected in the analysis in Chapter 5. The manufacturing stage is the second most energy- and GHG-emissions-intensive LCA stage, accounting for 5 to 15 percent of total vehicle life-cycle GHG emissions (Geyer 2008, Hakamada et al. 2007).

6.1.2 Approach to HD Vehicle Life-Cycle Assessment Literature Synthesis

NHTSA performed research to identify studies across a range of sources, including academic journals and publications of industry associations and non-governmental organizations. Appendix C lists all of the studies reviewed. Most of the studies identified were published within the last 10 years. NHTSA prioritized literature published in the last 3 years and LCAs specifically focused on HD vehicles and technologies, and NHTSA incorporates by reference the related LCA literature synthesis for light-duty vehicles reported in Chapter 6 of the *Final Environmental Impact Statement for Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks, Model Years 2017–2025* (the MY 2017–2025 CAFE standards Final EIS) (NHTSA 2012). The LCA literature shows general consistency in the findings between studies focused on HD vehicles and those focused on light-duty vehicles. Where findings are likely transferable to HD life-cycle considerations, light-duty studies further support the limited findings focused solely on HD vehicles.

6.1.3 Comparability of Life-Cycle Assessment Findings by HD Vehicle Type

The comparability of some LCA findings related to HD vehicles is made more complex due to the various types of HD vehicles in the national fleet and the applicability of different fuel-saving technologies. In addition to having more than one type of vehicle in a gross vehicle weight rating (GVWR) class, various types of vehicles can fall under one or more classes. For example, a city delivery van can fall under Classes 3, 4, or 5, depending on its weight. This section identifies general variations in LCA impacts among vehicle classifications and usage.

The life-cycle impacts of different sized vehicles are best compared using an appropriate functional unit. For vehicles that haul weights short distances, such as loaders, comparison on emissions per mile or per ton-mile will not be comparable to other vehicle classifications that are more focused on long-haul transportation. For these HD vehicles, the use-phase energy consumption is closely correlated with the weight of the vehicles and of the load. As an example, wheel loaders move heavy weight from one place to another; therefore, a functional unit of weight of stockpiled materials being moved and deposited is an appropriate functional unit (Salman and Chen 2013). Technologies that focus on aerodynamics or material substitution may not have much impact on the life-cycle impacts from wheel loaders, but technologies that decrease diesel consumption over the lifetime of the vehicle will. In the study by Salman and Chen, the authors show that a hybrid-powered L150G loader would have low CO_2 emissions during all phases by virtue of replacing some diesel consumption with electricity consumption from the grid. While these results are based on an analysis of off-road vehicles that are not covered under the current rule, NHTSA expects that the same impacts would apply for HD vehicles.

In freight transport, both the truck weight and the freight weight influence the life-cycle impacts of the vehicle. Therefore the functional unit of choice in LCAs is the ton-mile, which expresses the impacts of fuel efficiency with regard to freight carried. As the payload increases, the emissions on a ton-mile basis generally decrease. For example, Façanha and Horvath (2007) estimate that the CO_2 emissions from a

Class 2b (1.6 tons payload) freight vehicle average 289 grams (g) CO_2 per ton-mile, while emissions from a Class 5 (3.1 tons payload) freight vehicle average 230 g CO_2 per ton-mile, and emissions from a Class 8b (12.5 tons payload) freight vehicle average 187 g CO_2 per ton-mile.

6.2 Energy Source Life-Cycle Considerations

As discussed above, air quality and climate impacts reported in Chapters 4 and 5 include tailpipe emissions and upstream emissions from the production, processing, and distribution of fuels. To provide a point of reference, this section begins with a summary of the Annual Energy Outlook (AEO) 2015 forecast for HD fuel use, because analyses in Chapters 4 and 5 are consistent with AEO 2015 findings. Chapter 3 discussed in detail the current and projected transportation and HD fuel use from the AEO 2015 report, which has been summarized in this section. LCA literature on the types of energy consumed by HD vehicles and their LCA impacts are discussed in Sections 6.2.1 through 6.2.3. In the discussion that follows, emissions during use as well as upstream life cycle stages are considered for all HD vehicle energy sources.

The AEO 2015 estimated light duty vehicles in 2012 composed almost 60 percent of transportation fuel consumption and HD vehicles 22 percent. HD fuel consumption is projected to increase in overall share of total transportation energy consumption by 2040 due to an increase in HD fuel consumption (30 percent of total) and decrease in light-duty fuel consumption (46 percent). In 2012, the transportation sector made up 78.5 percent of total U.S. petroleum consumption, which is projected to decline by 3.6 percent by 2040. The AEO analysis also projects that petroleum will be the only U.S. fuel net import in 2040, primarily due to light and HD vehicle demands (EIA 2015).

Gasoline and diesel fuel accounted for 12.8 and 86.4 percent of HD vehicle fuel consumption in 2012, but both of these shares are projected to decline due to a rise of compressed natural gas (CNG) and liquid natural gas (LNG) use. LNG and CNG use is projected to increase from 0.2 to 6.3 percent by 2040. Diesel fuel will still compose the vast majority of fuel consumption in 2040 at 83.3 percent (EIA 2015).

Gasoline consumption in transportation is projected to decline, reflecting improvements in fuel economy and efficiency technologies in light-duty vehicles from Corporate Average Fuel Economy (CAFE) standards. These improvements are also projected to be integrated in HD vehicles as well, but to a lesser extent. Petroleum consumption will also decrease due to ethanol blending in gasoline (EIA 2015). Currently, almost all gasoline is blended to include 10 percent ethanol, and this share is projected to increase with the adoption of flex fuel vehicle technologies, which can currently accept ethanol blends of up to 85 percent (DOE 2016a).

AEO 2015 estimates that electricity use in the transportation sector was only 0.2 percent in 2012. While electric vehicle technologies continue to emerge and increase in adoption, electricity's share in 2040 is still projected to be less than 1 percent (EIA 2015).

Overall, AEO 2015 projects that, while HD vehicles will expand in alternative fuel use (i.e., LNG, CNG, biofuels, electricity) and improve in fuel efficiency, the sector will continue to be heavily dependent on petroleum, and diesel fuel in particular (EIA 2015).

The remainder of this section synthesizes life-cycle findings with regard to the following types of fuel sources for HD vehicles: diesel and gasoline, NG, and biofuels. LPG is primarily used in transit buses, and there is a lack of published LCA studies on other LPG vehicle applications due to relatively low use. Despite the relatively small current and projected use of NG, this section presents a more extensive discussion of LCA studies related to NG than petroleum, because the literature reveals more uncertainty on LCA impacts of NG vehicles and greater consensus on upstream emissions from petroleum production and refining. The synthesis of LCA studies related to biofuels is also relatively brief because the AEO 2015 does not forecast substantial changes in biofuel use, and this rulemaking is not expected to have a large impact on the extent of biofuel use.

6.2.1 Diesel and Gasoline

As noted above, the analyses in Chapters 4 and 5 include upstream and point-of-use fuel emissions, and the upstream percent of total emissions is consistent with LCA studies indicating that point-of-use fuel emissions account for approximately 75 percent of life-cycle vehicle GHG emissions in conventional internal combustion engine vehicles. These concordant findings reflect general consensus on upstream emissions associated with conventional oil production and refining, but there is less consensus on LCA impacts of unconventional sources of petroleum, including shale oil produced by advanced well completion processes involving fracturing (fracking) and petroleum from oil sands. Life-cycle considerations associated with fracking are similar for shale oil and for shale gas, and the LCA synthesis in Section 6.2.2.2, which focuses on shale gas, also addresses LCA considerations associated with shale oil. Therefore, the remainder of this section focuses on oil sand issues.

Oil sands, also known as tar sands or bituminous sands, are a mixture of sand and clay saturated with a thick blend of hydrocarbons. The United States predominantly imports oil sands-derived crude oil from Canada (Canadian National Energy Board 2014). Gasoline and diesel produced from oil sands can be substituted for gasoline and diesel produced from conventional sources without any modifications to vehicle equipment or changes in performance. From a life-cycle perspective, the sole difference occurs upstream in the life cycle during extraction and processing, resulting in additional GHGs and environmental impacts. As of 2013, the United States consumed 1.2 million barrels per day of oil sands-derived crude oil out of a total 18.9 million barrels of daily petroleum consumption, but this share is expected to increase as a result of new projects coming online (Canadian National Energy Board 2014).

A variety of studies have been published evaluating the well-to-wheels emissions associated with petroleum from oil sands, reaching a consensus that oils sands petroleum is more GHG-intensive to produce than conventional counterparts because oils sands require more energy to extract and process. Oil sands also have comparatively less hydrogen but contain higher amounts of impurities that require more energy-intensive processing prior to end use (Lattanzio 2014).

In addition to upstream GHG emissions from extraction and processing, the mining process for oil sands also impacts land to a higher degree than conventional oil extraction. Surface mining involves land clearance and extraction of shallow deposits, and in-situ recovery involves drilling wells and injecting steam underground to reduce bitumen viscosity. One study showed that land disturbance in Alberta ranges from 1.6 to 7.1 hectares per well pad, averaging 3.3 hectares. These impacts are significantly higher than land disturbance for conventional oil drilling in California, which averages 1.1 hectares per well (Yeh et al. 2010). Furthermore, land disturbance for oil sands extraction in Alberta has been shown to impact peat deposits, which results in additional life-cycle GHG emissions regardless of reclamation efforts. Changes in soil carbon stocks and biomass removal from surface mining emit 3.9 g and 0.04 g of CO_2 equivalent (CO_2e) per megajoule (MJ) of energy, respectively, from in-situ extraction of oil sands in Alberta.

The U.S. State Department commissioned a study for the Keystone XL pipeline project in both the 2011 Final Environmental Impact Statement and 2014 Final Supplemental Environmental Impact Statement, comparing the incremental GHG emissions associated with the pipeline to a selection of "reference crudes," defined as conventional crude oils available on the U.S. market. On a per-MJ basis, the well-to-wheels GHG emissions from Canadian oil crudes are 17 percent higher than those from the "average" barrel of crude oil sold in the United States (U.S. Department of State 2014). Most of this increase comes from the extraction and refining phase; the well-to-tank (i.e., upstream production) GHG emissions from oil sands crudes are 9 to 102 percent higher than emissions from conventional crudes (Lattanzio 2014).

The 2015 GREET model estimated the total lifecycle impact from diesel fuel production and use. Section XI of the Final Rule calculates GHG emissions estimates, expressed as CO_2e, by summing GREET's CO_2, methane, and nitrous oxide emissions estimates. Table 6.2.1-1 shows the combined results with a total of 95,668 grams per million (g/million) British thermal units (Btu). The tank to wheels emissions comprise the majority of total fuel emissions (83 percent of the well-to-wheels total).

Table 6.2.1-1. Estimated Diesel Fuel Lifecycle Greenhouse Gas Emissions (g CO_2e/million Btu)[4]

	Carbon Dioxide	Methane[a]	Nitrous Oxide[a]	CO_2e Totals
Well to Tank	13,792	2,025	79	15,896
Tank to Wheels	78,993	725	54	79,772
Well to Wheels	92,785	2,750	133	95,668

Notes:

[a] The values are calculated using 25 and 298 for the global warming potentials for methane and nitrous oxide, respectively.

Btu = British thermal unit; g = grams; CO_2e = carbon dioxide equivalent

6.2.2 Natural Gas

NG can be used in vehicles as CNG or LNG, and there is considerable interest in and uncertainty about the extent to which NG could become widely used in HD vehicles, specifically in Classes 7–8 freight trucks, which account for more than 80 percent of total Classes 3–8 freight truck fuel use (excluding bus fuel use). CNG in HD vehicles has advantages over LNG due to simplified distribution logistics with fewer opportunities for emissions leakage. However, LNG has 60 percent of the energy density of conventional diesel versus 25 percent for CNG. Due to the higher energy density, LNG is likely favored for use in long-haul trucking.[5] AEO 2014 forecasts that the NG share of new Classes 7–8 freight truck sales will fall from 1.2 percent in 2013 to 0.3 percent in 2017–2020, and then increase to 1.3 percent by 2025 and 11.3 percent in 2040. A recent study (Heath et al. 2014) cites other forecasts that NG vehicles could account for 20 to 40 percent of new Class 8 vehicle sales as early as 2020.

Section XI of the Final Rule includes a lifecycle analysis for natural gas-fuel HD vehicles and compares results with diesel fuel HD vehicles. Three scenarios were considered to evaluate both CNG and LNG HD vehicles. All scenarios included methane and nitrous oxide emissions. The scenarios also included a NG "thermal efficiency" factor. Thermal efficiency refers to the additional fuel required with NG from a lower engine compression ratio compared to conventional diesel. Natural gas powered engines require more fuel to compensate and move a vehicle the same distance. Driver behavior also influences thermal efficiency. Thermal efficiency is not an actual emissions source, yet it plays a role in an HD

[4] *See* Section XI of the Phase 2 Final Rule

[5] *See* Section XI of the Phase 2 Final Rule.

vehicle's emissions and is thus considered within the life cycle assessment.[6] Each of the scenarios includes a low and high thermal efficiency rating of 5 and 15 percent.

The first scenario is for current and future HD vehicles subject to the 2014 methane standard. For the 2014 and newer HD CNG vehicles in this scenario, the lower well to wheels total is 84,531 g/million Btu and the higher total is 92,266 g/million Btu. These emissions levels are 4 to 12 percent lower than conventional diesel emissions cited in Table 6.2.1-1 *(see* Scenario 1 CNG emissions values in Table 6.2.2-1).

The second scenario is for LNG powered trucks with average venting and low boil-off emissions. LNG is more likely than CNG to be used for long haul trucking given its higher energy density. Venting LNG to the atmosphere occurs when HD vehicle operators refuel and need to decrease the pressure in the fuel tank before additional fuel can be added. The recommended procedure is to transfer any remaining vaporized fuel back to the gas station or NG pipeline. Given regularly occurring delivery time pressures, HD operators may choose to vent the extra LNG to the atmosphere, rather than following the recommended procedure. LNG "boil-off" emissions occur when the fuel in a HD vehicle or retail facility storage tank warms the NG, which reaches the relief venting pressure threshold. The LNG average case assumes a modest quantity of refueling and boil-off methane emissions as estimated by GREET. In Scenario 2 the lower well to wheels total is 100,721 g/million Btu and the higher total is 109,912 g/million Btu. These emissions levels are 5 to 15 percent higher depending on the thermal efficiency factor[7] when compared with conventional diesel emissions cited in Table 6.2.1-1 (*see* Scenario 2 LNG emissions values in Table 6.2.2-1).

[6] *See* Section XI of the Phase 2 Final Rule.

[7] The thermal efficiency measures the engine's ability to convert thermal energy, or heat, into mechanical energy, or work. Increasing the thermal efficiency of an engine (i.e., pushing ratio of mechanical energy to thermal energy closer to one) can dramatically alter the engine's overall fuel economy and GHG emissions.

Table 6.2.2-1. Full Life Cycle Analysis Scenarios for CNG/LNG HD Vehicles (g CO_2e/million Btu)[8]

Fuel type and Scenario	Life Cycle Range	Carbon Dioxide	Methane[a]	Nitrous Oxide[a]	Thermal Efficiency 5%	CO_2e Totals (including 5% therm. efficiencies)	Thermal Efficiency 15%	CO_2e Totals (including 15% therm. efficiencies)
Scenario 1 (**CNG** 2014 or later truck)	Well to Tank	7,598	9,028	17	832	17,475	2496	19,139
	Tank to Wheels	60,702	2,724	596	3,035	67,057	9,105	73,127
	Well to Wheels	68,299	11,751	613	3,867	84,531	11,602	92,266
Scenario 2 (**LNG** 2014 or later truck; average vent and boil-off emissions)	Well to Tank	20,409	10,802	2.7	1,561	32,775	4,682	35,896
	Tank to Wheels	60,702	3,613	596	3,035	67,946	9,105	74,016
	Well to Wheels	81,111	14,415	599	4,596	100,721	13,787	109,912
Scenario 3 (**LNG** 2014 or later truck; high vent and boil-off emissions)	Well to Tank	20,409	10,802	2.682	1,561	32,775	4,682	35,896
	Tank to Wheels	60,702	24,005	596	3,035	88,338	9,105	94,408
	Well to Wheels	81,111	34,807	599	4,596	121,112	13,787	130,304

Notes:

[a] The CO_2e totals are calculated using 25 and 298 for the global warming potentials for methane and nitrous oxide, respectively.

Btu = British thermal unit; CO_2e = carbon dioxide equivalent; CNG = compressed natural gas; g = grams; LNG = liquefied natural gas

[8] *See* Section XI of the Phase 2 Final Rule.

The third scenario is for LNG powered HD vehicles with high venting and high boil-off emissions. The LNG high case assumes that the LNG storage tank is either vented to the atmosphere each time the driver refills the tank or that there is a boil-off event for each LNG tank filling. In Scenario 3 the lower well to wheels emissions total is 121,112 g/million Btu and the higher total is 130,304 g/million Btu. These emissions levels are either 27 or 36 percent higher than conventional diesel emissions cited in Table 6.2.1-1 (*see* Scenario 3 LNG emissions values in Table 6.2.2-1).

Section 6.2.2.1 summarizes literature assessing the impacts of upstream methane (CH_4) leakage associated with NG. Section 6.2.2.2 examines literature on shale gas production and hydraulic fracturing in more detail.

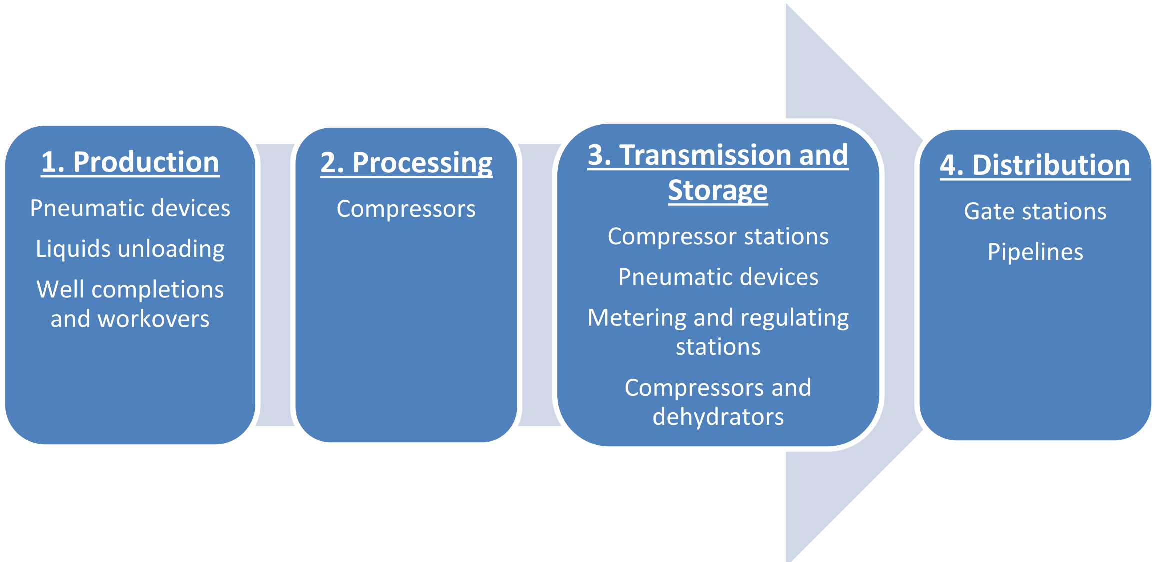
6.2.2.1 Methane Leakage

CH_4 accounts for an estimated 9 percent of total U.S. GHG emissions on a CO_2e basis. Between 1990 and 2012, annual CH_4 emissions decreased by 11 percent, largely as a result of emissions reductions from an EPA rule regulating landfills (Executive Office of the President 2014, EPA 2014a). However, in the United States annual total CH_4 emissions are projected to increase to approximately 8,570 million metric tons CO_2e ($MMTCO_2$e) by 2030; this is a 26 percent increase in annual emissions as compared to 2005 (EPA 2012f). To this end, a key highlight of the June 2013 Executive Office of the President's Climate Action Plan is to address and reduce CH_4 from four key sources: landfills, coal mines, agriculture, and oil and NG systems (Executive Office of the President 2013). Approximately 25 percent of the CH_4 emitted in the United States is attributed to NG systems, the second largest source of anthropogenic CH_4 emissions (EPA 2014a) after enteric fermentation (gas emitted by livestock).

CH_4 emissions occur at multiple points upstream of the end use of NG for industrial, power generation, and transportation purposes. NG systems consist of four major stages: production (i.e., extracting the NG), processing, transmission and storage, and distribution. CH_4 leakage occurs at a variety of points in these four stages.

Figure 6.2.2-1 identifies the main sources of CH_4 emissions during each of the upstream stages prior to NG consumption. EPA estimates that in 2012, the United States emitted 129.9 $MMTCO_2$e of CH_4 from upstream NG systems, of which 32 percent was from field production, 14 percent was from processing, 34 percent was from transmission and storage, and 20 percent was from distribution (EPA 2014a). These emissions do not include emissions related to use of NG (i.e., combustion of NG in vehicles).

Figure 6.2.2-1. Main Sources of Methane Leakage during Upstream Life-cycle Stages: Natural Gas Production, Processing, Transmission and Storage, and Distribution



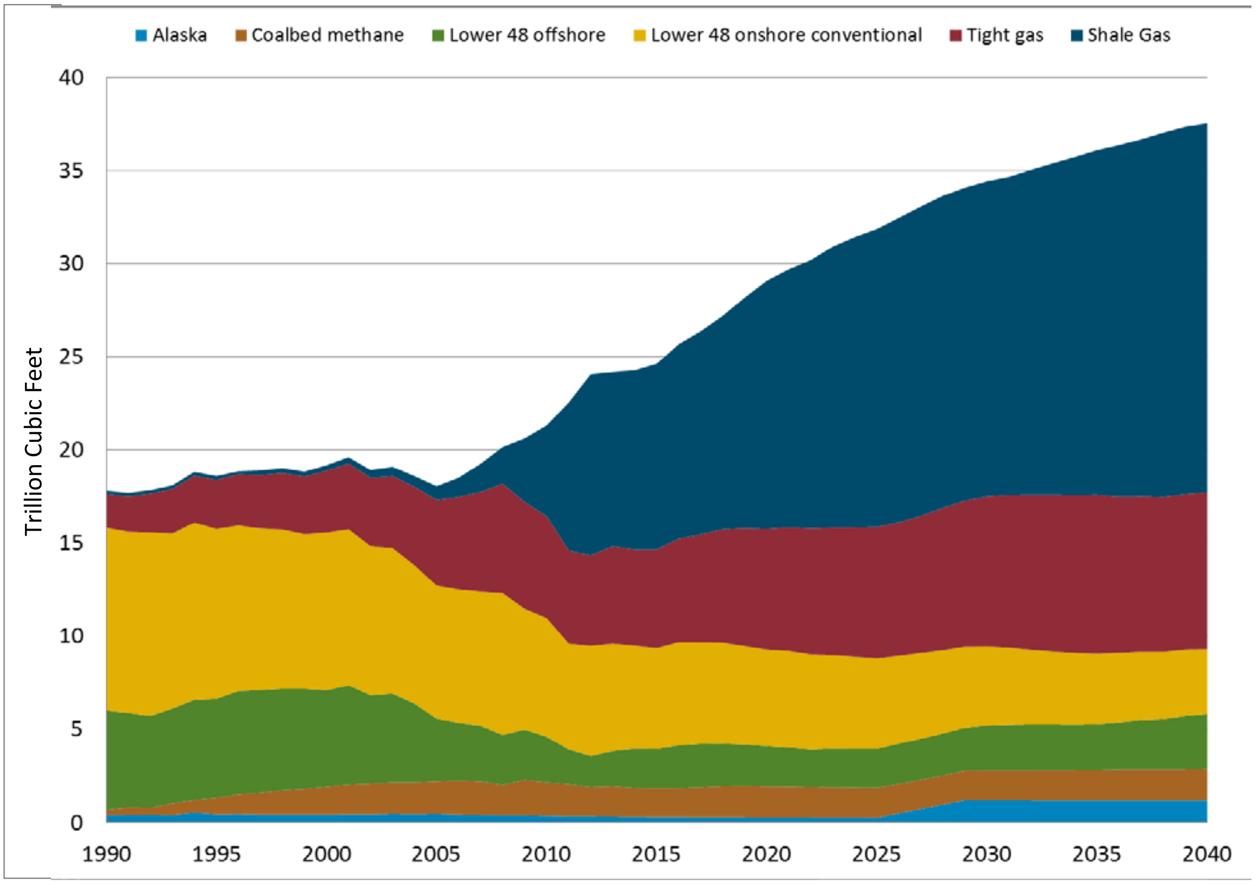
The main sources of CH_4 emissions during production are pneumatic devices,[9] liquids unloading, and gas completions and workovers with and without hydraulic fracturing (EPA 2014a). Raw NG is composed of CH_4 as well as other impurities. These impurities must be removed before the NG can be transported to prevent pipeline corrosion and in order for the NG to serve its end-use purpose. At processing facilities, the NG is separated from the other constituents of the raw gas. This requires maintaining certain levels of pressure during processing, and during the processing stage CH_4 emissions arise mainly from compressors (EPA 2014a). This processed gas is then sent to transmission systems to be transported to distribution systems, and hence to end-use consumption. In some instances the processed product is stored in underground formations or liquefied and stored above ground in tanks. Storage occurs during periods of low demand, and the NG is distributed during times of high demand. During transmission, CH_4 emissions mainly arise from the compressor stations, pneumatic devices, and from metering and regulating stations. When NG is stored, it can leak from compressors and dehydrators. During distribution, NG is emitted mainly from the gate stations and pipelines (EPA 2014a).

There has been recent increased market penetration of NG in the industrial, power, and transportation sectors, associated with increased United States production of NG in large part due to development of shale gas resources (Figure 6.2.2-2), which has resulted in lower prices. During the use stage, NG results in lower GHG emissions per unit of energy than other fossil fuels (EIA 2014g, 2014h). However, some argue that NG is not a better climate solution when considering the short-term GHG life-cycle perspective. A 2012 article in the Proceedings of the National Academy of Sciences states, "Recent reports in the scientific literature and popular press have produced confusion about the climate implications of natural gas. On the one hand, a shift to natural gas is promoted as climate mitigation because it has lower carbon per unit energy than coal or oil. On the other hand, methane, the prime

[9] EPA defines a pneumatic device as an automated instrument used for maintaining a process condition such as liquid level, pressure, pressure difference, and temperature (EPA 2014g).

constituent of natural gas, is itself a more potent GHG than CO_2; methane leakage from the production, transportation and use of natural gas can offset benefits from fuel-switching" (Alvarez et al. 2012).

Figure 6.2.2-2. U.S. Natural Gas Production by Source, Annual Energy Outlook 2014 Reference Case



Source: EIA 2014f.

There has been a wealth of recent research and literature around quantifying CH_4 leakage and understanding how to address this leakage. Some studies suggest that CH_4 leakage associated with NG extraction is higher than is accounted for in the U.S. national GHG emissions inventory.[10] Hamburg (2013) and Pétron et al. (2012) assert that fugitive CH_4 leakage at NG extraction sites is likely undercounted. At the end of the pipeline distribution system, several studies find that CH_4 leakage can occur in multiple locations near the point of use, although these emissions are highly variable and difficult to quantify (Jackson et al. 2014, Payne and Ackley 2012, Peischl et al. 2013, Phillips et al. 2012).

From the standpoint of comparing life-cycle electric utility emissions from different fossil fuels, even if system-wide leakage of NG is considerably higher than previously estimated, the incremental emissions are unlikely to be large enough to negate the climate benefits associated with switching from coal to NG (Brandt et al. 2014).

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[10] EPA publishes the Inventory of U.S. Greenhouse Gas Emissions and Sinks annually at http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

6.2.2.2 Shale Gas and Hydraulic Fracturing

Shale gas deposits consist of hydrocarbons trapped in fractures and pores of rock deep underground. The hydrocarbon content per unit of rock volume is significantly less than in conventional hydrocarbon reservoirs. Low permeability of the source rock and low energy density of the gas fields are driving factors for the upstream environmental impacts of hydraulic fracturing compared to conventional NG extraction.

Impacts of hydraulic fracturing result from three primary activities: supporting infrastructure, the drilling and fracturing process, and handling waste from the extraction process (Entrekin et al. 2011). Due to similarities between shale gas and shale oil deposits, many impacts of shale gas extraction are similar to those of shale oil extraction.

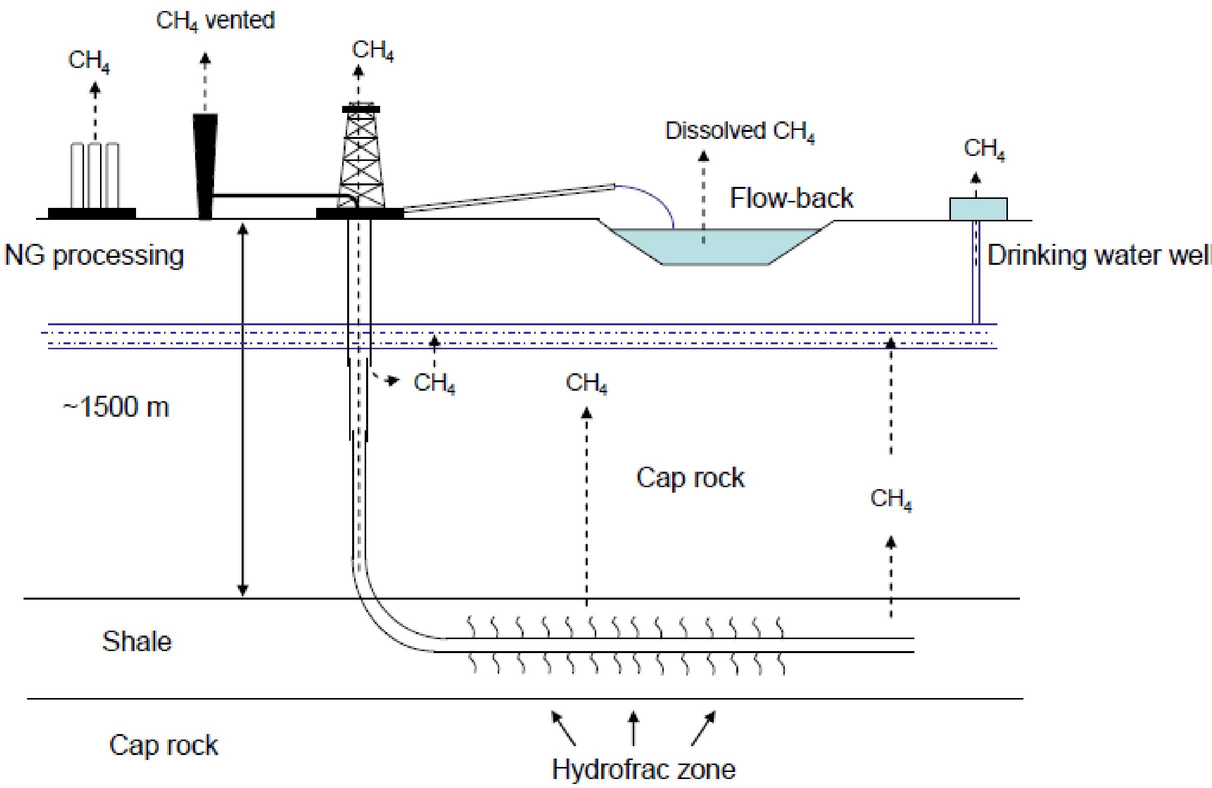
The low energy density of shale gas fields relative to conventional gas fields necessitates the construction of greater amounts of infrastructure (well pads, parking for employees, gas processing and transport facilities, and roads) to extract the gas. The primary metrics for evaluating the impact of this additional infrastructure include land use change and emissions from construction and operation.

Although an individual well pad typically occupies only 1.5 to 3.0 hectares of land (Entrekin et al. 2011), the low energy density of shale gas necessitates a well placement density ranging from 1.15 to 6 wells per square kilometer. In contrast, a conventional U.S. NG field has a density of only 0.38 well per square kilometer (Lechtenböhmer et al. 2011). The well pad density depends on the porosity of the underground shale and the relative shares of horizontal and vertical drilling operations. A representative multi-well pad size in the United States would occupy 16.2 to 20.2 hectares during operation and 4.0 to 12.2 hectares after partial restoration (Lechtenböhmer et al. 2011).

In addition to land use impacts, truck traffic to and from the wells generates both GHG emissions and criteria air pollutants, including particulate matter, sulfur dioxide, NO_x, non-methane volatile organic compounds, and carbon monoxide. Due to the greater numbers of wells and infrastructure, truck traffic servicing shale gas wells may be higher than for conventional gas wells, resulting in incremental emissions. The construction of roads and other infrastructure also increases runoff and sediment deposition in surface waters, negatively affecting ecosystems and increasing the risk of eutrophication (Entrekin et al. 2011).

In order to release NG from rock formations, a significant amount of energy must be used to fracture the rocks and bring the hydrocarbons to the surface, which releases CO_2 (and results in some CH_4 leakage, as described in Section 6.2.2.1). GHG emissions from fuel used for drilling can vary greatly depending upon the characteristics of the well being drilled. Some wells produce less gas and thus require more energy to bring it to the surface (Lechtenböhmer et al. 2011). In addition, higher CO_2 content in the extracted gas results in higher net emissions. Excluding CH_4 leakage, emissions for shale gas exploration, extraction, and processing are about 17.9 g of CO_2e per MJ of NG (Lechtenböhmer et al. 2011). For comparison, the fuel combustion emissions factors (tank to wheels) for 15-percent thermal efficiency in Table 6.2.2-1 range from 66.9 to 90.2 g CO_2e per MJ. A graphic depiction of CH_4 flows during hydraulic fracturing is shown in Figure 6.2.2-3. Drilling also uses large amounts of water, producing significant amounts of wastewater.

Figure 6.2.2-3. Methane (CH_4) Flows during Hydraulic Fracturing



Source: Lechtenböhmer et al. 2011.

In addition to CH_4 leakage into the atmosphere (discussed in Section 6.2.2.1), it is possible for CH_4 to enter groundwater via the fracking process. CH_4 emissions are difficult to measure because CH_4 has several routes of escape, including the "hydrofrac zone" in the shale formation, onsite aboveground wastewater pools, and through the drilling equipment. This waterborne CH_4 is a potential GHG source, because it can evaporate into the atmosphere when it reaches the surface. In some active gas extraction areas in the northeastern United States, CH_4 concentrations in drinking water wells ranged from 19.2 milligrams per liter to 64 milligrams per liter compared to background levels of 1.1 milligrams per liter (Lechtenböhmer et al. 2011). The extent to which CH_4 in groundwater is attributable to hydraulic fracturing compared to naturally occurring sources of CH_4 is uncertain.

Injecting fracturing fluid at high pressure into the shale and previously fractured "crack" rock formations creates a potential pathway for pollutants to enter groundwater at multiple stages of the drilling process. Fracturing fluid may contaminate the environment through surface-level spills, drill casing leaks, or leaks inside rock formations that have been fractured. In addition to a saline solution, fracturing fluids include undisclosed additives that serve to increase the efficiency of the fracturing process and encourage gas recovery by reducing friction and maintaining viscosity within the well. The composition of fracturing fluids varies, with over 2,500 hydro-fracking products containing over 750 different chemicals (Entrekin et al. 2011). Of the additives, ethylene glycol, diesel, formaldehyde, benzene, toluene, ethylbenzene, and xylene are all of concern to human health and the environment (Murill and Vann 2012). Only 10 to 30 percent of fracture fluids are typically recovered from wells, with the balance remaining in the environment (Ziemkiewicz et al. 2013).

Operation of NG extraction and processing equipment during the fracturing process releases non-GHG air pollutants, including aromatic hydrocarbons such as benzene (Howarth 2011). Air emissions show significant variation by region, with benzene concentrations much higher in the Barnett shale area of Texas relative to concentrations measured in Pennsylvania's Marcellus shale formation (Howarth 2011). Furthermore, onsite equipment operation has also been shown to contribute to ground-level smog formation due to emissions of smog-forming compounds (Howarth 2011, Lechtenböhmer et al. 2011).

A single well consumes 1,500 to 45,000 cubic meters of water over its lifetime and often receives repeated injections of fracturing fluid (Lechtenböhmer et al. 2011). The waste handling phase of hydraulic fracturing can result in pollution from "flowback"—i.e., fluid returning to the surface after being injected into underground rock formations. Flowback contains not only fracking additives, but may contain high levels of heavy metals, total dissolved solids, and trace amounts of radioactive elements from the rocks (Entrekin et al. 2011). Options for managing flowback include injection into abandoned gas or oil wells (not available in all locations), surface storage followed by treatment, or reuse in other well completions (Howarth 2011, Ziemkiewicz et al. 2013).

Surface storage and treatment are of particular concern, because CH_4 and other pollutants may leak from surface storage pools and tanks and contaminate groundwater and the atmosphere. Furthermore, municipal sewage treatment plants may be inadequate to treat toxic constituents of flowback and may release pollutants such as barium, strontium, and bromides into surface waters (Volz et al. 2011). Industrial wastewater treatment facilities are often better equipped to handle these pollutants; despite this advantage, they are not prevalent in the treatment of wastewater produced from hydraulic fracturing (Entrekin et al. 2011).

6.2.3 Biofuels

Within the realm of biofuels, this literature synthesis focuses on ethanol and biodiesel. Classes 2b–6 gasoline-powered vehicles are candidates for ethanol blend fuels. All diesel-powered HD vehicles are potential candidates for biodiesel blends.

6.2.3.1 Biodiesel

When used as a fuel in on-road vehicles, biodiesel offers significant GHG emissions advantages over conventional petroleum diesel. Biodiesel is a renewable fuel that can be manufactured domestically from used cooking and plant oils, as well as from animal fats, including beef tallow and pork lard. To produce biodiesel, oils and fats are put through a process called *transesterification*, which converts oils and fats by reacting them with a short-chain alcohol and catalyst to form fatty-acid methyl esters (NREL 2008). Biodiesel for sale in the United States must meet standards specified by American Society for Testing and Materials (ASTM) International. Biodiesel blends of 6 to 20 percent must meet ASTM D7467 specifications while "pure" biodiesel must meet ASTM D6751 specifications.

An EPA report on emissions from HD engines analyzed the results from 39 separate studies and found biodiesel use in on-road vehicles decreases tailpipe emissions of particulate matter, carbon monoxide, and hydrocarbons commensurately with blend level (EPA 2001). Although the report found a slight increase in NO_x, a 2006 analysis released by the National Renewable Energy Laboratory (NREL) found no significant increase in NO_x for biodiesel blends up to B20 (20 percent biodiesel, 80 percent petroleum diesel) (NREL 2006). A 2009 Society of Automotive Engineers report corroborated the results found in the NREL 2006 analysis and found that pure biodiesel (B100) increased NO_x emissions about 2 to 3 percent over conventional diesel emissions (Robbins et al. 2009). ANL's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool shows that replacing one single unit short-haul diesel truck with a comparable model running on B20 reduces GHG emissions by 5 tons annually. Reductions of other air pollutants, including carbon monoxide, NO_x, particulate matter, and volatile organic compounds, are comparable (ANL 2013).

Well-to-wheels analyses completed by NREL and ANL show that GHG emissions can be decreased by up to 52 percent when using biodiesel as a replacement for petroleum diesel (AFDC 2014a). ANL's GREET model estimates well-to-wheels emissions for petroleum diesel and biodiesel at 387 g of CO_2 per mile (g CO_2/mi) and 93 g CO_2/mi, respectively. These well-to-wheels emissions assume a soybean feedstock, which has lower life-cycle CO_2 emissions than algae feedstocks.

Petroleum diesel and biodiesel blends up to 5 percent biodiesel are considered "pure" petroleum diesel. Any higher biodiesel concentrations must be documented on a sticker prominently displayed on the fuel pump, as required by federal law. B20 and other lower concentration biodiesel blends can be used in nearly all diesel equipment with few or no engine modifications. B100 and other high level blends used in motors not recommended or approved by the manufacturer to use B100 can degrade and soften incompatible vehicle parts and equipment such as hoses and plastics. Starting in 1994, many engine manufacturers began replacing the vulnerable parts of the engine, including rubber components, with materials compatible with biodiesel blends. Because not all engines are compatible with higher level blends, NREL recommends contacting the engine manufacturer before using them (NREL 2008). Reducing the blend of biodiesel used in the winter months can avoid having biodiesel crystallize in cold temperatures. While biodiesel performance tends to improve in cold temperatures as the blend is reduced, additional measures such as incorporation of cold-flow additives can allow use of biodiesel blends up to B20 in cold weather conditions (AFDC 2015).

6.2.3.2 Ethanol

Although the use of high ethanol content fuel such as E85 is generally limited in HD vehicles, ethanol used as an on-road vehicle fuel has the potential to substantially reduce GHG emissions compared with conventional gasoline emissions, depending on feedstock and blend level. Most ethanol produced in the United States is manufactured from corn and other starch-based crops. However, ethanol also can be produced from cellulosic feedstocks like woody biomass and crop residue. Similar to biodiesel, when ethanol crops are grown they capture CO_2 and offset the GHG emissions later released through fuel combustion. The higher the blend of ethanol in the fuel, the lower the net GHG emissions.

Depending on the energy source used during production, corn-based ethanol can reduce well-to-wheels GHG emissions by up to 52 percent compared to gasoline (Wang et al. 2007). Cellulosic ethanol can create an even larger reduction in GHG emissions (around 86 percent reduction) (AFDC 2014b). The GREET model estimates well-to-wheels emissions for gasoline and pure corn ethanol to be 446 g CO_2/mi and 307 g CO_2/mi, respectively.

Most of the gasoline sold in the United States contains up to 10 percent ethanol (E10). All gasoline-powered vehicles are approved by EPA to use E10 in their engines because the fuel is considered "substantially similar" to gasoline. Regarding other low-level blends of ethanol, 15 percent ethanol and 85 percent gasoline (E15) was recently approved by EPA for use in conventional gasoline passenger vehicles of model year 2001 and newer. However, these blends generally are not suitable for most conventional HD engines (AFDC 2014c). Besides E10, the most commonly used blend of ethanol in the United States is a blend of gasoline and ethanol containing 51 to 83 percent ethanol (E85). Ethanol blends over E15, including E85, should only be used in flexible fuel vehicles (FFVs), because ethanol has a high alcohol content and can soften and degrade gaskets, seals, and other equipment in non-FFVs (DOE 2013b).

6.2.3.3 Indirect Land Use Change

Indirect land use changes occur when landowners make planting and harvesting decisions in response to market forces driven by biodiesel and ethanol production. As ethanol and biodiesel production increase, demand for feedstock crops increase and prices rise, thereby incentivizing landowners of grasslands and forest land to convert their acreage to grow crops instead. However, there is some controversy over whether increases in feedstock cause an increase in finished food product prices (e.g., corn, soybeans). A Congressional Budget Office (CBO) report estimates that ethanol production only contributed to between 0.5 and 0.8 percentage points of the 5.1 percent increase in food prices that occurred between April 2007 and April 2008 (CBO 2009). The amount of carbon stored per acre of cropland, including in soil, is generally less than that of forest or native grassland. There are widely differing viewpoints on the extent to which CO_2 emissions from indirect land use changes offset the emissions reductions associated with substituting biofuels for petroleum-based fuels. For example, a study by Searchinger et al. (2008) found that biofuels production in the United States using corn or switchgrass feedstocks will increase agricultural commodity prices, leading to extensive land-use changes and large net increases in GHG emissions. By comparison, a response by the U.S. Department of Energy (DOE) disputed many of the assumptions in Searchinger et al. (2008), with DOE suggesting that "it is reasonable to expect that rigorous, peer-reviewed, science-based land use models will show that indirect land use change impacts of biofuels production are far smaller" (DOE 2008). Experts differ on their opinions of the strength of the price signal in influencing landowners' decisions to convert to biofuel production; opinions also differ regarding the magnitude of change in carbon storage for land planted in biofuel crops versus land in its prior condition.

6.3 Materials and Technologies

This section reviews LCA literature related to six broad categories of materials and technologies that can improve HD vehicle fuel efficiency. Section 6.3.1 discusses manufacturing technologies that can reduce vehicle mass and weight. Section 6.3.2 reviews LCA impacts associated with mass reduction by material substitution. Sections 6.3.3 and 6.3.4 examine technologies related to tires and vehicle aerodynamics, respectively. Section 6.3.5 discusses trailers, and Section 6.3.6 examines hybrid vehicles and batteries. As noted in Section 6.1.1, for some of the studies considered in this chapter, the authors used existing models such as the GREET model to assess life-cycle emissions. While GREET has a module for upstream manufacturing energy and emissions for passenger cars and light-duty trucks, GREET does not assess upstream manufacturing energy and emissions for heavy-duty trucks at the time this analysis was conducted. Other studies included independent assessments of life-cycle implications using study-specific models developed from life-cycle inventory data sources.

6.3.1 Vehicle Mass Reduction by Manufacturing Technologies

Manufacturing technologies discussed in this section improve fuel efficiency by reducing vehicle weight. Certain manufacturing technologies can also reduce waste generated and provide energy savings from streamlined manufacturing that can further reduce the environmental impacts from across the vehicle life cycle.

6.3.1.1 Laser Welding

Standard arc welding techniques use an electrical arc to melt the work materials as well as filler material for welding joints, whereas laser welding joins pieces of metal with a laser beam that provides a concentrated heat source. One study of laser welding in production processes found improved and more efficient vehicle manufacturing and reduced material use for the same level of energy consumption (Kaierle et al. 2011).

6.3.1.2 Hydroforming

Hydroforming is the process of creating hollow metal structural parts from a tubular element that is shaped inside a mold by fluid under pressure, resulting in a reduced number of moldings required and lighter parts. The process allows manufacturers to produce entire components in a single process that would otherwise be made using multiple parts joined together. For example, a General Motors plant in Germany employed hydroforming technology and achieved a 20 percent reduction in the number of welding operations required (Galitsky 2008 citing GM 2001). Hydroforming has been applied to steel and aluminum automobile parts to reduce vehicle weight. Hydroforming has led to mass savings by eliminating the flanges required for welding and allowing for the use of thinner steel (Kocańda and Sadłowska 2008).[11] The use of hydroforming to manufacture a hollow crankshaft reduced material usage by 87 percent and resulted in a 57 percent weight reduction when compared to a solid shaft with the same torque formed from conventional welding techniques (Shan et al. 2012).

6.3.1.3 Tailor-welded Blanks

Tailor-welded blanks are an emerging weight-saving technology in vehicle manufacturing, in which two or more sheet pieces with different shapes, gages, and material specifications are welded together so that the ensuing sub-assembly is lighter and has few components (Rooks 2001). The use of tailored blanks eliminates the need for additional reinforcements and overlapping joints in a vehicle body, and it saves materials, further reducing the weight.

6.3.1.4 Three-dimensional Printing

Other opportunities for weight reduction in HD trucks may come from secondary mass reduction, whereby the size (and mass) of components is partially determined by the need to bear the mass of other components (Alonso et al. 2012). Therefore, if a vehicle's mass is reduced, the mass of some components can also decrease. This approach is applicable to both steel and aluminum parts.

Three-dimensional (3D) printing, also known as "additive manufacturing," is a collection of technologies capable of fusing materials to manufacture complex composite components in a single process step (Baumers et al. 2011). Because this technology allows the manufacturer to print the desired product with minimal support structures, 3D printing is expected to reduce the amount of materials used, wastes and recyclables generated, and the energy required to manufacture a product. Additive manufacturing on average uses 50 percent less energy and saves up to 90 percent on material costs compared to traditional manufacturing (Werrell and Femia 2012).

3D printing in vehicle manufacturing has been mostly limited to prototyping of components as a design and engineering tool, and has been used to make small parts for visual analysis, but has otherwise been seldom used to produce final production parts in vehicles (Richardson and Haylock 2012). Because additive manufacturing is a new and evolving technology, peer reviewed studies have been limited on the topic and focus their scope only on the creation of small parts in the manufacturing process. As the technology continues to evolve and penetrates the manufacturing sector, additional research and targeted studies should provide better insight into potential energy savings.

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[11] Kocańda and Sadłowska (2008) did not perform an LCA of hydroforming but instead discussed the mass savings achieved from the production technology.

6.3.2 Vehicle Mass Reduction by Material Substitution

Reducing vehicle mass through material substitution has implications across the life cycle of a vehicle, including 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. Replacing materials such as conventional 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 titanium.

6.3.2.1 Aluminum and High-Strength Steel

Aluminum, which is used intensively in the transportation sector, combines a high strength-to-weight ratio, corrosion resistance, and processability, and can be used as a substitute for heavier conventional steel (Cheah et al. 2009). High-strength steel has the same density as conventional steel, but provides greater strength, so less high-strength steel is required to fulfill the same function as conventional steel. Aluminum and high-strength steel can reduce weight while providing strength and rigidity similar to conventional steel. Aluminum is lighter than the conventional steel it replaces, and high-strength steel saves weight by using less material to provide the same level of strength. Aluminum is a suitable substitute for cast-iron components, molded steel parts such as wheels, and stamped-steel body panels, while high-strength steel provides the greatest weight-reduction benefits in structural or load-bearing applications, rather than non-load-bearing uses, where strength is less of a factor in material selection (Cheah and Heywood 2011, Kim et al. 2010b, Koffler and Provo 2012, Mohapatra and Das 2014).

Two studies in the literature synthesis focus on LCA impacts of substituting aluminum for conventional steel components in HD vehicles.[12] One study determined that increased energy use and GHG emissions associated with producing HD truck aluminum wheels substituted for conventional steel wheels were offset by use-stage savings after 224,000 miles of travel (Koffler and Provo 2012). A separate study found that a 13.4 percent reduction in MD truck mass through material substitution with aluminum decreased life-cycle energy consumption by 209.3 gigajoules compared to a baseline vehicle using comparable steel components, and a 3.2 percent mass reduction in HD bus mass through material substitution with aluminum reduced life-cycle energy consumption by 484.3 gigajoules (Song et al. 2009).[13]

Many studies emphasize the sensitivity of LCA results to the amount of recycled material used in vehicle components and the materials recycling rate at end of life. One study suggested that aluminum supplies will likely be easier to access in the future through secondary sources (i.e., recycling aluminum through

[12] The following studies 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: Koffler and Provo (2012), Kim and Wallington (2013b), Kim et al. (2010a), Geyer (2007, 2008), Dubreuil (2010), and Birat et al. (2003). All of the studies reviewed have undergone peer review for publication in academic journals, with the exception of Koffler and Provo (2012), which underwent a critical review but has not been published in an academic journal. Certain studies noted where critical reviews were conducted in accordance with ISO 14044 standards on either the methodology (Geyer 2008), life-cycle inventory inputs (Dubreuil 2010), or both (Koffler and Provo 2012), or where critical review was not performed (Bertram et al. 2009).

[13] The authors chose to evaluate an Isuzu N-series medium-duty truck with a total curb weight of 3,600 kilograms and a Provost Car XLII bus with a total weight of 16,980 kilograms. Both vehicles are a subset of HD vehicles as defined in this EIS.

"landfill mining" or "urban mining") than through primary aluminum (i.e., from bauxite mining) (Chen and Graedel 2012a). This suggests that the quality of secondary aluminum will impact the cost and supply of aluminum used in vehicles in the future. Aluminum alloy scrap accumulates alloy elements, resulting in loss of quality when recycled. Avoiding quality loss will require identifying and segregating alloys at the point of discard so that the alloy can be reused as originally designed (Chen and Graedel 2012b). The region where an aluminum smelter is located also adds variation to GHG emissions because aluminum's carbon intensity is strongly tied to the electricity grid's carbon intensity in the smelter's region, with a 479 percent difference in emissions factors depending on how the electricity is generated (Colett 2013).

Many other studies examine life-cycle impacts of substituting aluminum and/or high-strength steel in light-duty vehicles, or vehicles in general, with some studies focusing on material substitution in specific vehicle components and other studies estimating overall mass reduction from material substitution and vehicle redesign (Bandivadekar et al. 2008, Bertram et al. 2009, Birat et al. 2003, Cáceres 2009, Das 2014, Dubreuil et al. 2010, Geyer 2008, Hakamada et al. 2007, Kim and Wallington 2013a, Kim et al. 2010a, Lewis et al. 2014, Lloyd and Lave 2003, Mayyas et al. 2012, Stodolsky et al. 1995, Ungureanu et al. 2007, Weiss et al. 2000). A detailed discussion of studies related to light-duty vehicles was presented in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS.

Both the HD and light-duty vehicle literature support the following findings from the MY 2017–2025 CAFE standards Final EIS:

- In general, 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.
- The magnitudes of life-cycle GHG-emissions reductions and energy-use savings are influenced by the amount of recycled material used in vehicle components, the end-of-life material recycling rate, the lifetime of vehicles in use, and the location of aluminum production.

6.3.2.2 Polymer Composites

Glass- and carbon-fiber-reinforced polymer composites, including bio-based and nanocomposites, offer high strength-to-weight ratios, thermal and flame resistance, enhanced barriers that reduce or eliminate gas permeation, and corrosion resistance (Khanna and Bakshi 2009). Song et al. (2009) found significant use phase energy savings from substituting composite components for steel in a medium-duty truck and a bus, with use phase energy savings from composites over 2.5 times better for the bus than the truck due to the longer useful life and distance traveled for buses.

Most of the LCA literature on composites examines applications in light-duty vehicles (Boland et al. 2014, Cheah 2010, Das 2011, Gibson 2000, Lloyd and Lave 2003, Keoleian and Kar 1999, Khanna and Bakshi 2009, Overly et al. 2002, Tempelman 2011, Weiss et al. 2000). The detailed discussion of studies related to light-duty vehicles was presented in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS and supported the following findings that are also likely to be applicable to HD vehicle composite applications:

- Polymer composites (including those reinforced with glass, carbon fiber, or nanoclays) used in vehicle body panels are generally more energy- and GHG-intensive to produce compared to conventional steel, but greater or less than aluminum depending on the study. However, energy-efficient manufacturing processes, such as the pultrusion, injection molding, and thermoforming processes, can make fiber-reinforced composites less energy intensive to produce relative to both steel and aluminum.

- Carbon-fiber-reinforced polymer composites used for specific automotive parts (e.g., a floor pan) are typically less GHG-intensive across the life cycle (including end of life) than similar components made from conventional materials, but the magnitude of the difference depends on the vehicle weight reduction due to the composite materials.
- The use of polymer composites in vehicle body panels and air intake manifolds leads to reduced energy use and GHGs emitted over the vehicle life cycle compared to vehicles with similar aluminum or steel parts. This reduction is due to significant reductions in vehicle weight and associated improvements in fuel economy.
- For other environmental impact categories (e.g., acidification, water use, water quality, landfill space), polymer composite materials also tend to result in overall lower life-cycle impacts compared to conventional steel and to aluminum.
- Composites are more difficult to recycle than their metal counterparts. Some studies assign a credit for incineration of composites in a waste-to-energy plant, but this could overstate composites' life-cycle benefits compared to metals if this energy-recovery option is unavailable. In general, end-of-life assumptions and the post-consumer material content of composite materials have not been studied as thoroughly as other life-cycle phases.

6.3.2.3 Magnesium and Titanium

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 steel it typically replaces, but it offers significant fuel economy improvements due to a 60 percent weight reduction. Titanium is denser than magnesium, but it provides the highest strength-to-weight ratio of all metals. It can also offer significant fuel economy savings, but it is costly. Depending on the alloy used, both magnesium and titanium offer comparable strength and durability performance relative to more commonly used materials such as steel but at a lower density.

Manufacturing magnesium into automotive components presents an additional environmental burden over manufacturing steel, with an energy demand that ranges from 8 to 10 times that of conventional steel manufacturing (Cheah 2010). Magnesium components have been determined to have 2.25 times the impact on human toxicity as steel (including respiratory effects, ionizing radiation, and ozone layer depletion) (Witik et al. 2011). A study by Witik et al. (2011) found that human toxicity impacts of the magnesium material and manufacturing phase outweigh avoided impacts during the use phase relative to steel. End-of-life recovery of magnesium is fairly common, with recovery rates in excess of 90 percent (Ehrenberger 2013), comparing favorably with recovery rates for steel and aluminum. The energy associated with magnesium recycling is very small compared to the energy used to manufacture automotive components from virgin magnesium. The emissions solely from magnesium recovery during vehicle disposal are 1.1 kg CO_2e per kg of magnesium (Ehrenberger 2013). Because this value is much lower than that of virgin magnesium—typically about 20 to 47 kg CO_2e per kg of magnesium—incorporating recycled magnesium in vehicles can yield significant energy savings.

Compared to literature regarding magnesium, the literature characterizing the life-cycle impacts of titanium components in vehicles is more limited, with little recent research available on the subject. Gibson (2000) found that the energy and emissions associated with titanium manufacture were the highest of the light-weighting techniques studied. Although titanium has a higher mass-to-strength ratio than magnesium, it offers less direct mass savings over steel because it is heavier than magnesium (disregarding uses in specialized, load-bearing components).

The current literature review did not locate studies examining the life-cycle impacts of magnesium and titanium substitution in HD vehicles. However, the detailed discussion of studies related to light-duty vehicles presented in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS supported the following findings that are also likely to be applicable to magnesium and titanium substitution in HD vehicles:

- 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 by substituting magnesium and titanium for heavier components, but break-even distances (at which fuel economy savings outweigh increased production energy) can be relatively high in relation to other materials. Break-even distance declines with higher proportions of recycled magnesium.

6.3.3 Tires

Tires impact vehicle fuel economy through rolling resistance, defined as "the energy consumed by a tire per unit of distance traveled" (Mammetti et al. 2013). The vehicle's engine converts the chemical energy in the fuel into mechanical energy, which is transmitted through the drivetrain to turn the wheels. Rolling resistance is a force at the wheel axle in the direction of travel required to make a loaded tire roll. As a result, the engine must consume additional fuel to overcome the rolling resistance of the tires when propelling the vehicle (NAS, 2006). For a Class 8 tractor-trailer, this resistance accounts for 13 percent of energy used at a highway speed of 65 mph (TIAX 2009). Changes to the physical design of tires can reduce the energy needed to overcome rolling resistance, leading to reductions in fuel consumption. For example, rolling resistance can be reduced through the use of low rolling resistance (LRR) tires and wide-base single (WBS) tires, which are wide tires that replace dual tire sets, and through implementation of tire pressure systems to keep tires at a higher pressure. LRR and WBS tires may already make up half the tractor-trailer market (Sharpe and Roeth 2014).

A study by Surcel and Michaelsen (2010) examined the influence of installing WBS tires on the drive axles alone, as well as drive axles and semi-trailer axles together. During several short-term tests, the WBS test tires resulted in fuel savings of 9.2 to 9.7 percent when compared to the control dual tires when placed on both drive and trailer axles. When placed on just the drive axles, the fuel savings were more modest, ranging from 0.8 to 5.1 percent, depending on the WBS tire model used. The authors also conducted long-term tests of two vehicles with dual tires driven over 100,000 kilometers during a 5-month period, followed by WBS tires installed on one vehicle while the other continued to use dual tires. Both vehicles then traveled over 175,000 kilometers during a 10-month period that showed an average reduction in fuel consumption of 5.11 percent for the truck with WBS tires, leading to an estimated net reduction in annual fuel consumption of 7,947 liters.

Surcel and Michaelsen (2010) also conducted short-term fuel consumption tests that replaced drive axle tires with LRR tires, which resulted in modest fuel savings of 1.4 to 2.4 percent, depending on the tire model used. In long-term tests, tandem axle trailers equipped with side skirts and LRR tires that traveled over 84,000 kilometers during a 7-month period showed an average reduction in fuel consumption of 6.27 percent compared to a control vehicle, leading to an estimated net reduction in annual fuel consumption of 1,574 liters.

A study by Mammetti et al. (2013) substituted a "normal" HD vehicle tire with a LRR tire through variations in tread pattern and rubber compound and found that a rolling resistance reduction of 0.45 kilograms per metric ton (kg/T) of vehicle mass resulted in a fuel consumption reduction of 1.15 liters per 100 kilometers, or 0.49 gallons per 100 miles. This equates to a fuel reduction of approximately 1.09 gallons per 100 miles for each kg/T reduction in rolling resistance.

A study by Bachman et al. (2005) examined the impact on fuel economy and NO_x emissions resulting from use of WBS tires on Class 8 tractor-trailers in a track test simulation of real world operating conditions. Across the testing conditions, use of WBS tires resulted in fuel economy improvements of 6.04 to 12.6 percent, when measuring fuel economy in miles per gallon. The results also showed reductions in NO_x emissions of 13.9 to 36.9 percent when measuring emissions in grams per distance traveled.

LaClair and Truemner (2005) used software to model the effect of tire rolling resistance on HD vehicle fuel consumption. Assuming a baseline average rolling resistance coefficient of 6.22 kg/T, the authors examined the effects of rolling resistance reductions. The study found fuel savings of 1.40 and 1.62 liters per 100 kilometers (0.60 and 0.69 gallons per 100 miles) for each kg/T reduction in rolling resistance for secondary road driving and highway road driving, respectively.

In addition to LRR and WBS tires, rolling resistance can be reduced through the use of tire pressure systems, which monitor low pressure and automatically inflate tires to reduce the energy loss incurred from under-inflated tires. This intervention can result in a fuel consumption reduction of about 1 percent (Sharpe and Roeth 2014, TIAX 2009).

Studies and agencies have found significant benefits in fuel efficiency and maintenance needs in maintaining adequate tire pressure. In 2010, the California Air Resources Board (CARB) mandated that all automotive service providers check and inflate tires to acceptable pressures as part of any maintenance or repair service in an effort to curb GHG emissions (CARB 2010). Tire pressure management systems (TPMSs) address this need by providing constant feedback to users on the state of tire inflation. NHTSA (2012) estimated the fuel economy (MPG) using tire survival probabilities and expected miles traveled for a range of vehicle ages (light-duty trucks and vans). The study determined that TPMSs provided fuel efficiency savings of 0.1 to 0.3 percent for vehicles over 4 years in age (Sivinski 2012). The report vetted these findings with a literature review, where fuel efficiency savings from TPMSs averaged 0.3 percent over six studies. While this analysis focused on light-duty trucks and vans, similar results are expected for HD vehicles. Another study by Ogunwemimo (2011) found that underinflation (measured through pressure) of tires by 20 percent resulted in a 3-percent drop in fuel economy for trucks and trailers. For maintenance needs, this study estimated that over 50 percent of truck and trailer breakdowns were tire-related, and not maintaining ideal tire pressure can reduce a tire's lifetime by up to 20 percent (Ogunwemimo 2011). Automatic tire inflation systems (ATISs) expand on TPMS services by continually maintaining a desired tire pressure by providing compressed air from a truck's air brake reservoir. One report found that these systems could struggle to maintain proper inflation when air pressure is being lost at a high rate through tire leaks (Freund and Brady 2009), suggesting that ATISs used in conjunction with TPMSs could offer the greatest efficiency benefits. Further research is needed to better quantify environmental impacts of TPMSs and ATISs across the entire life cycle.

The studies discussed above show fuel use and emissions reductions from tire substitution during the use of HD vehicles, but the literature review did not identify HD vehicle LCA studies that examined impacts from other stages of the tire life cycle, including manufacturing, retreading, and end-of-life management specific to LRR and WBS tires. For light-duty vehicles, NHTSA (2009) found no significant relationship between rolling resistance and traction except for "wet slide" performance, where there was a strong and significant relationship between lower rolling resistance and poorer performance in wet slide conditions. The authors note that this correlation may be especially important to vehicles without anti-lock braking systems (ABS) because the wet slide coefficient relates most closely to locked-wheel emergency stops. NHTSA also subjected five tire models to on-vehicle tread wear testing and found no clear relationship between tread wear and rolling resistance levels. For six tire models subjected to significant wear during indoor tests (i.e., in a laboratory setting when not attached to a vehicle) the results did show a trend toward faster wear for tires with lower rolling resistance. It is unclear to what extent these light-duty results would apply to tires on HD vehicles.

Other anecdotal and qualitative sources indicate that production and use of tires designed to reduce rolling resistance may have impacts on tire manufacturing energy, durability, and opportunities for retread. A report from the North American Council for Freight Efficiency (NACFE 2010), based on data obtained from HD vehicle fleets in North America, noted that WBS tires could have effects on life-cycle impacts of tires compared to normal dual tires, such as weight reductions, increased brake life, and some difficulties with retreading. A reduction in durability and retread opportunities could decrease the effective life of the tires, creating more waste and requiring additional tire manufacturing. A paper prepared by the American Trucking Associations noted that WBS tires offer advantages in weight and fuel savings and increased brake life. However, WBS tires could also lead to a 25 to 35 percent reduction in miles to removal and higher failure following retread (Routhier 2007). A presentation from Michelin indicates that manufacturing a WBS tire could require 15 gallons of oil compared to 24 gallons required for manufacturing two dual tires (Johnston, undated).[14] The information currently available suggests that LRR and WBS tire production could lead to both reductions and increases in environmental impacts relative to conventional dual tires. Further research is needed to better quantify environmental impacts of LRR and WBS tires across the entire life cycle.

6.3.4 Aerodynamics and Drag

About two-thirds of the fuel used to propel trucks is consumed due to aerodynamic drag from trucks at highway speeds (ATDynamics 2014a). As the vehicle moves, drag originates in four major sections: the front, the gap between the trailer and the tractor, the undercarriage, and the rear. The rear sections alone account for approximately 75 percent of the total drag (ATDynamics 2014a). Trucking fleet tractors and trailers can be equipped with efficiency technologies that can reduce drag. While these technologies increase the gross weight of vehicles and trailers, several studies show that fuel efficiency savings from the reductions in aerodynamic drag are greater than the additional fuel needed to transport the additional weight, thus reducing net fuel consumption.

Aerodynamic technologies for tractors and trailers include gap reducers, side skirts, boat tails, end fairings, and advanced trailer skirts. All of these technologies, often called "fairings," reduce turbulence and improve fuel efficiency. A CEM (2009) study showed cab roof fairings achieved 6 to 8 percent fuel savings, adjustable cab roof deflectors achieved 2 to 4 percent savings, trailer side skirts achieved 4 to 7 percent savings, and trailer rear fairings achieved at least 1 percent savings in fuel consumption (CEM 2009). Another study found that the use of fairings, often in combination, can reduce fuel consumption by 6.4 percent, resulting in a reduction of about 0.925 metric tons CO_2 per truck on a monthly basis (Galipeau-Belair et al. 2013). A variety of materials are used for aerodynamic technologies, as summarized in Table 6.3.4-1. For each technology type, the reported materials used, fuel savings, and additional weight are listed.

[14] Similarly, a commenter provided a summary table from a 2013 Michelin truck tires LCA report that suggested the potential for life cycle benefits. However, because the underlying analysis was not provided, NHTSA cannot verify the methodology, underlying assumptions, or results. *See* Chapter 9 for additional information.

Table 6.3.4-1. Summary of Currently Available Aerodynamic Technologies

Aerodynamic Technology	Company	Materials Used	Weight Added (lbs.)	Manufacturers' Claimed Fuel Savings (%)[a]
Trailer Gap Reducers	Freight Wing	Thermoplastic PolyOlefin (TPO)	55	2
Trailer Boat Tails	Aerodynamic Trailer Systems	Polymer Skins, Steel Bolts and Aluminum Rails	130	4–7
	Slipstreem Aerodynamics		150	3–4
	ATDynamics	Thermoplastic Composite, Galvanized Steel	115–165	5.1–5.5
	SmartTruck Systems	TPO, Linear Low Density Polyethylene	210–300	5.5–10
Trailer Side Skirts (full vehicle kit)	Aero Tech Fleet Products	TPO	190	7
	Fleet Engineers	Aluminum	199	6
	Freight Wing	Polypropylene thermoplastic	170	7.45
	Edge Skirts	Thermoplastic composite	106–170	7.3
	Silver Eagle	Aluminum and Steel	390	5.7
	SA Concepts	Aluminum and Rubber Impact Guard	180	4
	ATDynamics	Thermoplastic Composite, Stainless Steel	105–175	4–7
	Wabash Composites	HDPE and Steel	256	5–6
	Ridge Corporation	Patented high impact material	200	5.2–7.2
	Strehl	Steel Composite with polyethylene core TPV Rubber	223	7

Notes:

[a] Manufacturer's claimed fuel savings are based on values reported by manufacturers for each combination of aerodynamic technology and material used. These claimed fuel savings are not normalized to a common baseline, drive-cycle, or vehicle. These claimed fuel savings were not independently verified by NHTSA. This table is not intended to serve as a comprehensive list of available aerodynamic technologies and does not serve as an endorsement of any technology, product, or company. The United States Government does not endorse products or manufacturers.

Sources: Aero Tech 2014, ATDynamics 2014b, ATDynamics 2014c, ATS 2014, EcoVet Furniture 2014, Edge Skirts 2014, Fleet Engineers 2014, Freight Wing 2014a, Freight Wing 2014b, Ridge Corporation 2014, SA Concepts 2014, Silver Eagle 2014, Slipstreem 2014, SmartTruck 2016a, SmartTruck 2016b, Strehl 2014, Wabash Composites 2014.

lbs = pounds

A recent study by DOE's Vehicle Technologies Office notes that a full truck and trailer aerodynamic package can weigh up to 4,000 pounds (DOE 2013c). The additional cumulative weight of adding one or more pieces of aerodynamic technology to a HD vehicle could impact the overall cargo capacity and freight efficiency when calculated on a delivered ton-mile per gallon basis. Therefore, mass-reduction technologies, as described in Sections 6.3.1 and 6.3.2, can help maximize fuel efficiency while minimizing or eliminating the additional weight and subsequent impacts on freight efficiency (DOE 2013c).

Additional research is needed on this topic to determine the life-cycle impacts of applying aerodynamic technologies with respect to freight efficiency and mass-reduction technologies.

The studies discussed above indicate that fuel savings resulting from aerodynamic technologies exceed the additional fuel demand resulting from the added weight of aerodynamic materials during vehicle use. Additional life-cycle impacts are associated with the manufacturing, transport, and disposal of aerodynamic technologies, but this literature review did not locate any studies that specifically assessed impacts from manufacturing, transport, and disposal of aerodynamic technology. Further research is needed on this topic, but many of the materials commonly used for aerodynamic technologies are also used for vehicle mass reduction, discussed in Section 6.3.2.

Most of the available scientific literature is focused on technologies for reductions in aerodynamic drag for trucking fleet tractors and trailers. However, technologies may allow for fuel economy improvements in other HD vehicle segments, including Classes 2b–3 vehicles and vocational vehicles. NHTSA does not assume that vocational vehicles will require aerodynamic improvements to comply with the new standards. However, NAS (2010) reported the possible aerodynamic improvements for vocational vehicles could yield 0.5 to 3 percent improvements in fuel economy, depending on the aerodynamic device and the duty-cycle average speed. A full aerodynamics package offered a 1.5 percent improvement in fuel economy for a straight box truck operating at an average speed of 30 mph.

6.3.5 Trailers

Tractor-trailers are the largest consumers of fuel within the HD vehicle sector and therefore offer significant opportunity for reductions in environmental impacts through efficiency improvements (Façanha et al. 2012). With the exception of refrigeration systems, vehicle trailers do not themselves consume energy or generate GHG emissions during use, but improvements in trailer design can affect the overall efficiency of freight transit by reducing fuel consumption associated with the ton-miles of freight hauled. Trailers can contribute as much as 34 percent to the total drag of a tractor-trailer (Sharpe and Roeth 2014). In response to rising fuel costs, lower adoption costs, and environmental regulations (including both EPA's SmartWay Transport Partnership and California Air Resources Board's Tractor-Trailer Greenhouse Gas regulation), vehicle trailer technologies have been widely adopted in the past decade by medium- and large-scale shipping fleets and will continue to be adopted by increasing numbers of operators within the timeline of this EIS.

Trailer refrigeration systems, used to provide trailer cooling for transport of fresh and frozen foods, are typically powered by small diesel engines. Research has suggested that trailer refrigeration systems powered by electricity could decrease the life-cycle environmental impacts from refrigerated trailers. A demonstration project by Shurepower, LLC for the New York State Energy Research and Development Authority and the EPA SmartWay Transport Partnership evaluated the environmental benefits of switching from a trailer refrigeration unit (TRU) powered by diesel fuel to a hybrid diesel-electric trailer refrigeration unit (eTRU) partly powered by grid-supplied electricity. The results of the analysis show that the switch from conventional diesel TRUs to eTRUs resulted in net emissions reductions of 6.982 grams per kilowatt-hour (g/kWh) of NO_x, 0.522 g/kWh of particulate matter up to 10 micrometers in size (PM10), and 5.427 g/kWh of CO. The hybrid diesel-electric TRUs consumed 15.75 percent less diesel fuel than trucks equipped with conventional diesel-powered TRUs, offering corresponding decreases in GHG emissions (Shurepower 2007).

Many design considerations for efficient trailers are based on efficiency principles for vehicle technology discussed in other sections this chapter, including aerodynamics, mass reduction, and tire technologies. The current literature review did not locate data on the life-cycle environmental impacts from measures and technologies specifically designed to reduce the weight of trailers (e.g., studies quantifying the manufacturing, use, and end-of-life environmental impacts of vehicle trailer components), but it is likely that materials and technologies used for trailers will include the aerodynamics, mass reduction, and tire technologies discussed above. Further research is needed on this topic.

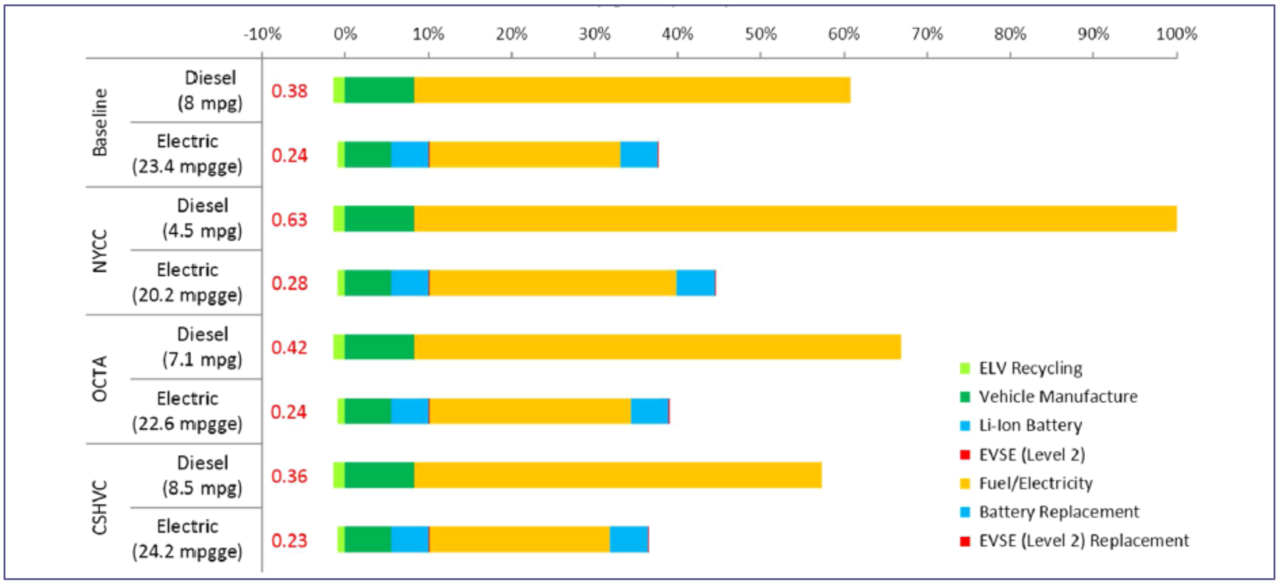
6.3.6 Hybrid Vehicles, Batteries, and Fuel Cells

Electric vehicles (EVs) use battery technologies to provide power, thereby reducing or even eliminating liquid fuel consumption during vehicle operation. EVs cover a range of different engine 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, DOE 2013d). BEVs are purely electrically powered and do not incorporate an internal combustion engine. HEVs incorporate a battery and electric motor combined with an internal combustion engine (or fuel cell), and have on-board charging capabilities (e.g., regenerative braking). PHEVs are fitted with a large capacity rechargeable battery that can be charged from the electric grid; like HEVs, they also use an internal combustion engine or fuel cell as backup when battery power is depleted. The DOE Fuel Cell Technology Office is currently investigating the feasibility of fuel cell electric trucks (FCET) that are operated with a fuel cell-dominant powertrain along with a small battery for braking and acceleration events.

An accounting of the life-cycle environmental impacts of BEVs and PHEVs includes upstream impacts from generating electricity, which depends on the efficiency of power plants and the mix of fuel sources used, also referred to as the “grid mix.” Chapter 6 of the MY 2017–2025 CAFE standards Final EIS presented an extensive discussion of this issue. Grid electricity is not expected to account for a significant share of fuel use in HD vehicles, but HEVs are likely to be used in an increasing share of Classes 2b–6 pickups, vans, and vocational vehicles. Therefore, the LCA literature review in this section focuses on materials and technologies associated with HEVs (many of which are also applied in BEVs and PHEVs).

Although BEVs and PHEVs are not expected to account for a significant share of HD vehicles, it should be noted that there are viable options for full electrification for urban delivery vehicles of gross vehicle weight (GVW) Classes 4−6 (6,350−11,800 kg, or 14,001−26,000 lbs.) (Feng and Figliozzia 2012). The relative benefits of electric trucks depend heavily on vehicle efficiency associated with drive cycle, diesel fuel price, travel demand, electric drive battery replacement and price, electricity generation and transmission efficiency, electric truck recharging infrastructure, and purchase price. For a drive cycle with frequent stops and low average speeds in urban settings, electric trucks emit 42 to 61 percent fewer GHG emissions and consume 32 to 54 percent less energy than diesel GVW Classes 4–6 trucks, depending upon vehicle efficiency cases (Lee et al. 2013). Studies demonstrate that over a range of driving conditions electric trucks have lower emissions than conventional diesel engines, as shown in Figure 6.3.6-1. The ranges of GHG emissions provided in Lee et al. (2013) reflect differences in the mix of fuels used to generate grid electricity used in electric trucks; the comparisons with diesel GVW Classes 4–6 trucks cover the full life cycle (i.e., they include upstream and downstream emissions).

Figure 6.3.6-1. HD Vehicle Life-Cycle Emissions Comparisons between Conventional Diesel and Electric Power for Delivery Trucks in Gross Vehicle Weight Class 5 (16,001–19,500 lbs.)[a]



[a] Comparative scenarios are for cities with varying representative driving cycles. NYCC is for dense urban driving, similar to New York City; OCTA is for a bus route with medium distances between stops, similar to transit in Orange County; And CSHVC is for a delivery truck in a combination of suburban and urban settings.

mpg = miles per gallon; mpgge = miles per gallon gasoline equivalent; NYCC = New York City Cycle; OCTA = Orange County Transit Authority Bus Cycle; CSHVC = City-Suburban Heavy Vehicle Cycle; ELV = End-of-Life Vehicle; Li-ion = lithium ion; EVSE = Electric Vehicle Supply Equipment [e.g., charging station]

Source: Lee et al. 2013.

HEV drive trains for GVW Classes 4–6 trucks can achieve fuel savings of up to 17 percent, and can be financially attractive for HD vehicle operators. One study also reports that maintenance requirements associated with hybrid-diesel are significantly better than conventional diesel (Eick 2012). A special application in HD trucks is freight delivery to and from marine ports, which requires very low speed driving in the port area, where HEVs can operate in the electric mode at low speed and with the engine off at idle (Zhao et al. 2013). Ports are ideal locations to reduce HD vehicle emissions with HEVs because truck freight traffic can be the single largest source of air pollution in coastal cities (Vujičić et al. 2013). Another study finds that HEV Class 8 HD vehicles achieve the highest performance in city driving with stop-and-go conditions that regenerate the battery and minimize durations at cruising speeds (Daw et al. 2013).

Although nickel-metal-hydride batteries are used in hybrid vehicles, lithium-ion (Li-ion) batteries offer lightweight properties, lower maintenance requirements, and minimal self-discharge characteristics, enabling Li-ion batteries to stay charged longer. The trend for HD vehicles with electric power drive is toward Li-ion batteries (Majeau-Bettez et al. 2011, Notter et al. 2010). Li-ion batteries consist mostly of heavy metals and plastics (Notter et al. 2010), with lithium itself representing a small fraction (typically between 1 and 3 percent) of total battery composition (Gaines et al. 2011).

One LCA study found that environmental impacts associated with HD Li-ion battery pack production is significantly higher than for a conventional diesel engine. For example, a battery pack with 140 kWh energy capacity provides close to the minimum performance required for larger HD vehicles. The GHG emissions needed to produce a 140 kWh Li-ion battery pack are estimated to be 37 $MTCO_2e$, considerably higher than the 3 $MTCO_2e$ for a conventional battery used with 8-liter 6-cylinder diesel engines. In addition, the HD vehicle itself has a functional lifespan twice the Li-ion battery, which will necessitate at least one replacement, thereby doubling the associated "cradle to gate" associated emissions (Vujičić et al. 2013). Another study, by Sardar and Mubashir (2011), showed that the energy and GHG emissions from Li-ion battery manufacturing constitute a relatively small share of the full life-cycle energy and GHG emissions from a CNG PHEV urban city bus. This study, citing Samaras and Meisterling (2008), found that the total energy required for battery production was 311.1 gigajoule, or 5 percent of life-cycle energy consumption, and total CO_2 emissions from battery manufacturing were 53.14 metric tons, or 6.5 percent of life-cycle CO_2 emissions.

The detailed discussion of studies related to light-duty EVs presented in Chapter 6 of the MY 2017–2025 CAFE standards Final EIS supported the following findings, which are also likely to be applicable to HD vehicles:

- Across the full vehicle life cycle, including the use stage, the impacts of upstream battery production are small (less than 10 percent across most environmental impact categories).
- Life-cycle emissions from BEVs and PHEVs vary based on the electricity grid mixes used for battery charging. Section 6.2.2 of the MY 2017–2025 CAFE standards Final EIS describes the life-cycle impacts of varying grid-mix assumptions.
- Most studies have not quantified the environmental impacts from recycling Li-ion batteries. The recycling market for Li-ion batteries is in its infancy, with limited feedstock, because EVs are still just a small segment of the vehicle market.

6.3.7 Truck and Tractor Engine Idling

HD vehicle engine idling has recently been targeted as an area for environmental improvement. Vehicle engines are idled in order to power climate-control devices and sleeper compartment accessories in tractors during long-haul trips. HD vehicle engines are estimated to be idling 20 to 40 percent of their operation time, depending on the engine operation and season (Brodrick et al 2002). EPA estimated that 960 million gallons of fuel are consumed per year from idling commercial trucks alone, and the associated emissions from these activities account for 11 million tons of CO_2, 180,000 tons of NO_x, and 5,000 tons of particulate matter (Frey and Kuo 2009). This section details three options for reducing engine idling: auxiliary power units (APUs), reducing heating and cooling loads through direct-fire heaters (DFHs, also known as fuel-operated heaters) and other technologies, and automatic engine stop-start systems.

APUs are designed to provide energy or electricity to vehicle tractors separate from the vehicle engine. As they are designed for just auxiliary power demands rather than vehicle propulsion, APUs are a more efficient option than vehicle idling for powering climate-control devices and other tractor accessories. Direct emissions from APUs are required to comply with small engine standards, and California requires additional emissions controls, such as a diesel particulate filter, for APUs on trucks built in 2007 or later (Gaines and Brodrick Hartman 2009). Two categories of APU technologies are commonly used in HD vehicles: external diesel power generator units and fuel cell units (both proton exchange membrane and solid oxide fuel cells).

Diesel-powered APUs have been shown to be an environmentally beneficial alternative to HD vehicle idling. A study by EPA (Lim 2002) evaluated the direct emissions reduction associated with a 2-cylinder diesel-powered APU when compared with idling a HD truck's engine for 3 hours. The author performed 42 tests on nine Class 8 trucks ranging in model year from the 1980s to 2001. The results show that the model year 2000 truck equipped with an APU was capable of reducing CO_2 emissions by 50 to 81 percent and NO_x emissions by 89 to 96 percent (Lim 2002). A study by Frey and Kuo (2009) showed similar findings when comparing an idling baseline engine with two diesel-powered APUs at various electrical loads (6 kW and 4 kW) over the course of a year. The diesel power generator APUs were estimated to reduce direct NO_x emissions by 80 to 90 percent and direct CO_2 emissions by 36 to 47 percent at mild ambient temperatures when compared with the default base engine idle speed of 600 revolutions per minute. Overall, the diesel APUs evaluated showed lower hourly energy use (gallons per hour) as well as fewer emitted pollutants per hour. The base case had an hourly energy use rate of 0.56 to 0.71 gallons-equivalent per hour, depending on if the air conditioning was on, whereas the APUs had an hourly energy rate of 0.22 to 0.55 gallons-equivalent per hour depending on the APU's power and the load. However, these energy and emissions savings do not account for the upstream emissions from the extraction and production of diesel fuel or from the manufacturing and transportation of the APU (Frey and Kuo 2009).

Currently available diesel-powered APUs have higher particulate matter emissions rates than the truck engine idling they replace because APU engines are currently required to meet less-stringent EPA emissions standards for particulate matter than those for truck engines. As a result, in the Notice of Proposed Rulemaking (NPRM) and the Draft EIS EPA projected an increase in particulate matter emissions associated with Class 7–8 combination vehicles due to increased use of APUs under the Phase 2 standards. In its Final Rule, EPA is adopting a new PM emissions standard that applies exclusively to APUs. This standard will result in a lower increase in diesel PM emissions from APUs used on combination tractors than was projected in the Draft EIS. EPA expects that diesel particulate filters (DPFs) will be the usual control technology employed to meet this new standard.

Fuel cell APUs have also emerged as an option for reducing the environmental impact of idling HD trucks. Proton exchange membrane (PEM) fuel cells use a proton-conducting polymer membrane as their electrolyte, which is sandwiched between two porous electrodes. As the fuel is fed into one side, the electrode splits it into protons and electrons. While the protons flow through the electrolyte, the electrons flow through the wires connecting the electrodes, creating a current. When the protons and electrons meet, they produce water as a waste stream (Barbir 2006). PEM fuel cells use hydrogen or methanol for fuel, operate at ambient temperature, and offer reductions in environmental impacts compared with both diesel APUs and engine idling (Barbir 2006, Brodrick et al. 2002). However, these studies have not evaluated the upstream emissions associated with the extraction and production of the fuel and the manufacturing of the fuel cell. Because PEM fuel cells are fueled by hydrogen, they have zero direct emissions of NO_x (Brodrick et al. 2002). However, PEM fuel cells have a very low tolerance for impurities in their fuel, requiring a supply of onboard hydrogen and thus making them less likely to be widely deployed (Jain et al. 2006). Solid oxide fuel cells (SOFCs) have a similar structure to PEM fuel cells but have an oxide-based ceramic electrolyte typically made of yttria-stabilized zirconia and can operate on diesel fuel (Brodrick et al. 2002). They operate at high temperatures (800 to 1,000°C) but are more tolerant to sulfur containments, which are typically found in diesel fuel (Jain et al. 2006). They produce the equivalent amount of power as a diesel generator with 46 percent less fuel, reducing direct emissions (Jain et al. 2006). The battery technologies discussed in Section 6.3.6, primarily Li-ion chemistries, could be used for APUs in place of fuel cells or fossil fuels; that section details the life-cycle implications of using these battery alternatives. Biofuels have also been highlighted as a possible fuel source for SOFCs. Lin et al. (2011) notes that to supply 1 kWh of electricity, biodiesel produced from waste cooking oil has a life-cycle energy impact eight times less than that of an idling diesel engine. Further discussion of the life-cycle impacts of biofuels can be found in Section 6.2.3.

The life-cycle environmental impacts from APUs beyond the vehicle use phase are briefly covered in the literature. The results for both diesel-powered and fuel cell APUs indicate reduced energy use and some emissions when compared with idling a vehicle's engine for an extended period of time. A study by Gaines and Brodrick Hartman (2009) presents the life-cycle impacts of idling an HD truck engine running on conventional diesel fuel containing 500 parts per million sulfur with heating and cooling loads compared with a diesel-fueled APU with the same capacity for an average of 2,100 hours per year. Over the full diesel fuel cycle—including upstream fuel extraction, processing, and transport—the APU had an order of magnitude less CO_2 emissions when compared with idling. The annual energy use for the heating and cooling loads was three times less for the APU than engine idling (Gaines and Brodrick Hartman 2009). However, this analysis did not account for environmental impacts from manufacturing and transporting the equipment studied or end-of-life impacts and noted that no published measurements are available for APUs using ultra-low sulfur diesel fuel.

A study by Baratto and Diweker (2005) evaluates the life-cycle environmental impacts of a small-scale SOFC system with an output of 1 to 10 kW as compared with internal combustion engine idling. The authors evaluated the environmental impacts from "all steps required to provide the fuel, to manufacture the [APU] device and to operate and maintain the vehicle through its lifetime up to disposal" but do not include impacts from disposal. The impacts from the APU are compared with the impacts from the internal combustion vehicle, including the "emissions from operation over a life time, fuel life cycle and system life cycle." The study results are normalized over a lifetime of 9,090 hours and evaluate a multitude of human health and environmental factors, including global warming potential, acidification, and human inhalation and dermal exposure. The authors found that the output rate of potential environmental impacts per second of diesel consumption for an internal combustion engine idling over the lifetime of the technologies is three orders of magnitude larger than that of the SOFC analyzed (Baratto and Diweker 2005).

The literature review did not identify life-cycle studies quantifying either the environmental impacts from disposal of APUs or the fuel or freight efficiency impact from the APU's additional weight. APUs can weigh up to 600 lbs. (DOE 2013c). Additional research is needed on this topic to determine the life-cycle impacts of applying APUs with respect to production, disposal, freight efficiency, and vehicle fuel economy.

DFHs reduce engine idling time by using a separate fuel combustion system designed to provide heat to both the cab and sleeper in place of engine heating. These systems operate by turning on when a temperature threshold is reached to automatically heat the cabin. Engines are about 10 percent efficient in providing heat from a diesel fuel source, whereas DFHs have an efficiency of 80 to 85 percent (Stodolsky et al. 2000). Stodolsky et al. (2000) estimated the fuel efficiency savings in providing heat to be 80 percent higher with DFHs. The study also estimated DFHs to cut heating air pollution by 99 percent for VOCs and THCs, 99.5 percent for CO, and 86 percent for CO_2. However, the study did not differentiate between engine idling fuel consumption/emissions for heating purposes from other needs, making it unclear how much of total engine idling fuel consumption or emissions can be directly related to heating (Stodolsky et al. 2000). Lim (2002) also assessed the environmental benefits of DFHs through data measured from extensive engine experiments. The study found DFHs to reduce fuel consumption for heating by 94 to 95 percent while curtailing NO_x emissions by 99 percent (Lim 2002). Battery powered automatic cooling systems, similar in function to DFHs, are also being used by Volvo to improve fuel economy (FleetOwner 2016).

Cabin temperature-related savings can also be achieved by reducing cooling loads. Solar control glazings and ultraviolet (UV) protective glasses reflect sunlight to better regulate temperature without added cooling requirements. Tavast (2007) experimented with five different types of truck glasses to measure internal temperature. The study found maximum temperature savings to be 5°C and irradiance savings of 90 W/m^2 (Tavast 2007).

Automatic stop-start systems have primarily been implemented in passenger and light-duty vehicles, automatically shutting down the engine during any stoppage or idling time. Atabani et al. (2011) estimated that these systems increase vehicle fuel economy by 8 percent, although the study did not detail the specific type of vehicle that was being assessed. The authors expected stop-start systems to be most effective for vehicles that use significant amounts of electricity to support accessories (Atabani et al. 2011).

For DFHs, other technologies to reduce heating/cooling loads, and stop-start systems, the available studies focused on fuel savings in the use phase. Further research is needed to better quantify environmental impacts of these technologies across the entire life cycle.

6.3.8 Transmission-Efficiency Technologies

Integrating advanced transmissions improves the efficiency of engine operations. These advancements include incorporating a higher number of gears, and technologies such as dual clutch and automatic transmissions. Reports on the efficiency benefits from these systems have focused on light- and medium-duty passenger vehicles, but have revealed significant fuel economy savings. One report found that increasing total gear options from 4 to 5 to 8 in light- and medium-duty vehicles increases fuel efficiency by 2 to 8 percent, as increasing gear numbers allows smaller engines to efficiently power larger vehicles or improves performance of existing engines (DOE 2016b). Another report found that using automatic transmission systems, which reduce friction through a hydraulic shifting system, increase vehicle fuel efficiency by 6.3 to 11 percent in a range of passenger vehicles (Moawad and Rousseau 2012). Dual-clutch transmissions, which also cut down on friction and energy losses in transmission, were found to improve efficiency in mid-size passenger vehicles by over 10 percent (Moawad and Rousseau 2012).

Heavy duty vehicle manufacturers have begun implementing direct-drive top gear systems, similar to overdrive systems, which increase the gear ratio between engine and wheels, allowing the vehicle to sustain speed while reducing engine rotation. The National Academy of Sciences found that a recently developed direct-drive top-gear system produced vehicle fuel savings of 1.5 percent (NAP 2015). Outside of gear-shifting technologies, the eCoast system automatically disengages the transmission system to save fuel while the vehicle is coasting on slopes. eCoast uses a software algorithm to maintain speed and ensure safe operations during these coasting periods, providing similar fuel efficiency benefits to hybrid vehicles over long hauls at a significantly lower cost (NAP 2015). While these technologies and systems provide fuel savings in operations, NHTSA's review found that the current literature is lacking in studies quantifying environmental impacts of these technologies from the entire life cycle outside of vehicle operations. Further research is needed to quantify additional life cycle impacts.

6.4 Conclusions

The information in this chapter helps the decisionmaker by identifying the net life-cycle environmental reductions in environmental impacts achievable by various fuels, materials, and technologies, and the factors that contribute to increases or decreases in environmental impacts at other life-cycle stages beyond the vehicle use stage. The overarching conclusion based on this synthesis of the LCA literature considered is that most materials and technologies addressed appear to reduce GHG emissions, energy use, and most other environmental impacts when considered on a life-cycle basis. However, some technologies show uncertainty about environmental impacts from upstream production, which may, in some cases, counterbalance some portion of the environmental benefits when evaluated on a life-cycle basis.

6.4.1 Energy Source Conclusions

The LCA literature synthesis revealed qualitative information about upstream NG and petroleum emissions to supplement the analyses in Chapters 4 and 5. In general, the LCA literature synthesis found that upstream emissions make up less than 20 percent of total life-cycle GHG emissions of most non-GHG life-cycle emissions.

The following tentative findings emerged from the LCA literature synthesis for energy source technologies:

- Likely alternative fuels for HD vehicles, compared with conventional truck fuels, produce net lower life-cycle GHG emissions.
- CNG and LNG powered HD vehicles can produce net lower life-cycle GHG emissions than vehicles powered by conventional diesel.
- The upstream environmental impacts associated with extraction methods and methane leakage of natural gas are lower than the upstream impacts (extraction and refining) liquid petroleum.
- Biodiesel life-cycle emissions are lower than life-cycle emissions from conventional diesel.
- Both ethanol and electric power are applications that could also reduce the life-cycle emissions for trucks but are not expected to comprise a significant part of future truck fleets.

6.4.2 Materials and Technologies Conclusions

The magnitude of life-cycle impacts associated with materials and technologies likely to be used to improve HD vehicle fuel efficiency is small in comparison with the emissions reductions from avoided fuel consumption during vehicle use. This LCA literature synthesis identified some qualitative information about those impacts to supplement the analyses in Chapters 4 and 5.

The LCA literature synthesis revealed the following trends for materials and technologies considered.

- Materials manufactured using aluminum, high-strength steel, composites, magnesium, and titanium require more energy to produce than similar conventional steel components.
- Weight-reducing manufacturing—such as hydro-forming, laser welding, and 3D printing—requires new equipment to produce HD vehicles.
- However, upstream energy requirements associated with the new equipment are small compared to the operating efficiencies gained, leading to a net decrease in environmental impacts assessed in the literature.
- Upstream energy requirements associated with the alternative materials are small compared to the operating efficiencies gained, leading to a net decrease in GHG emissions.
- The adoption of HD hybrid and APU technologies is also likely to yield lower environmental impacts on a life-cycle basis for some pollutants, although increased APU use may cause an increase in particulate matter emissions.
- There are performance trade-offs associated with aerodynamic features and LRR tires. Aerodynamic features add weight and have associated upstream energy requirements. The current state of LCA scientific understanding on aerodynamic features and LRR tires is still evolving and more research is needed to assess impacts upstream and downstream of these products.
- For several technologies—including trailers, aerodynamics and drag, tires, truck and tractor idling, and transmission-efficiency technologies—further research is needed on life-cycle impacts.

CHAPTER 7 OTHER IMPACTS

This chapter describes the affected environment and environmental consequences of the Final Action and alternatives on potential impact areas other than those described in Chapter 3, Chapter 4, and Chapter 5 of this EIS. These additional potential impact areas include hazardous materials and regulated waste (Section 7.1), historic and cultural resources (Section 7.2), noise (Section 7.3), safety impacts on human health (Section 7.4), and environmental justice (Section 7.5). This chapter also addresses unavoidable adverse impacts (Section 7.6), short-term uses and long-term productivity (Section 7.7), and irreversible and irretrievable commitments of resources (Section 7.8). With respect to each of these issues, because the magnitude of the changes that each alternative would generate is too small to address quantitatively, impacts on the resources and topics discussed in this chapter are described qualitatively in relation to the Final Action. Consequently, the discussions of impacts in this section do not distinguish among the alternatives.

With regard to Section 7(a)(2) of the Endangered Species Act (16 United States Code [U.S.C.] § 1536(a)(2)), NHTSA incorporates by reference its response beginning on page 9-101 of the MY 2017–2025 CAFE Standards Final EIS (NHTSA 2012). For that rulemaking, NHTSA concluded that a Section 7(a)(2) consultation was not required because any potential for a specific impact to particular listed species and their habitats associated with emissions changes achieved by that rulemaking were too uncertain and remote to trigger the threshold for such a consultation. That conclusion, based on the discussion and analysis included therein, applies here to the fuel consumption and greenhouse gas (GHG) emissions reductions anticipated to occur under the Final Action.

7.1 Hazardous Materials and Regulated Waste

7.1.1 Affected Environment

Hazardous waste is defined here as any item or agent (biological, chemical, or physical) that has the potential to cause harm to humans, animals, or the environment, either by itself or through interaction with other factors. Hazardous waste is generally designated as such by individual states or the U.S. Environmental Protection Agency (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. For the Final Action and alternatives, the relevant sources of impacts from hazardous materials and waste are oil extraction and refining processes, agricultural production and mining activities, and vehicle batteries.

Hazardous waste produced from oil and gas extraction and refining can present a threat to human and environmental health. Onshore environmental effects are most commonly caused by the improper disposal of saline water that was produced with oil and gas (referred to as “produced water”), the accidental releases of hydrocarbons and produced water, and the improper sealing of abandoned oil wells (Kharaka and Otton 2003). Produced water from oil and gas wells often contains high concentrations of total dissolved solids in the form of salts. These wastewaters could also contain various organic chemicals, inorganic chemicals, metals, and naturally occurring radioactive materials (EPA 2016f).

The development of new techniques, such as hydraulic fracturing, has led to vast new reserves of natural gas becoming available in the United States, with new potential environmental effects to drinking water. The extraction of natural gas from shale can affect drinking water quality as a result of gas migration, contaminant transport through fractures, wastewater discharge, and accidental spills (Vidic et al. 2013).

This has led some states, including New York, Illinois, Pennsylvania, and Colorado, to limit hydraulic fracturing near aquifers (FracFocus 2014). In 2015, EPA conducted an *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water*, which concluded that while certain hydraulic fracturing activities have the potential to impact drinking water resources through certain mechanisms (such as water withdrawals, fracturing into drinking water resources, migration of liquids and gases underground, and inadequate treatment and discharge of wastewater), there is no evidence that such mechanisms have impacted drinking water resources in the United States in any widespread or systematic way. EPA did identify specific cases where drinking water resources had been impacted by hydraulic fracturing activities, but concluded that the number of these cases were small compared to the overall number of hydraulically fractured wells in the United States. EPA does note, however, that their failure to find significant widespread effects of hydraulic fracturing activities on drinking water resources within the United States might be a result of other limiting factors, such as insufficient data on the quality of existing drinking water resources, a paucity of long-term studies, the presence of other sources of contamination, and the inaccessibility of certain information on hydraulic fracturing activities and their impacts (EPA 2015i).

Offshore environmental effects from oil and gas extraction can result from the release of improperly treated produced water into the water surrounding an oil platform (EPA 1999b). Offshore platform spills, although relatively rare,[1] can have devastating environmental impacts. According to the American Petroleum Institute, oil and gas production generates more than 18 billion barrels of waste fluids, including produced water and associated waste, annually in the United States (EPA 2012b).

The oil extraction process used to produce fuel for the operation of motor vehicles generates emissions from the combustion of petroleum-based fuels. These emissions, which include volatile organic compounds (VOCs), sulfur oxides (SO_X), nitrogen oxides (NO_X), carbon monoxide (CO), particulate matter (PM), and other air pollutants, can affect air quality (NAP 2015). In the atmosphere, SO_X and NO_X contribute to the formation of acid deposition (the deposition of SO_X and NO_X under wet, dry, or fog conditions, commonly known as “acid rain”), which enters bodies of water either directly or as runoff from terrestrial systems (*see* Chapter 4 for more information on air quality), with negative impacts on water resources, plants, animals, and cultural resources. Oil extraction activities could also affect biological resources through habitat destruction and encroachment.

In 2015, EPA outlined a series of steps it plans to take in order to address methane and smog-forming VOC emissions from the oil and gas industry. These steps include using regulatory and voluntary approaches to reduce methane emissions from new sources; building on the 2012 New Source Performance Standards; discussing the use of new equipment and processes with industry, state, and tribal leaders; extending VOC reduction requirements to existing oil and gas sources by issuing Control Technique Guidelines; and expanding the Natural Gas STAR Program (EPA 2015j).

The production and disposal of batteries is another relevant source of potential impacts related to regulated waste. Batteries, such as those used in hybrid vehicles, are considered universal waste by EPA (40 Code of Federal Regulations [CFR] Part 273) and can therefore be recycled under the streamlined collection standards that facilitate environmentally sound collection and proper recycling and treatment.

[1] Historically, there were six spills per one hundred billion barrels of oil produced from offshore oil platforms between 1964 and 2010 (Anderson et al. 2012).

HD vehicles could incorporate hybrid power trains and on-board energy storage systems (batteries). Hybridization is considered most beneficial in transit buses, Class 2b pickups and vans, Class 8 refuse trucks, and Classes 3–6 box and bucket trucks (ORNL 2013). Battery-powered motors are not as practical for long-haul HD trucks with high daily vehicle miles traveled (VMT) but could be an option for service fleets, such as Classes 2b–3 vehicles, that perform local deliveries or other jobs during the day and can be plugged in and charged overnight (NRC 2014). The range of commercial electrochemical battery types that are either currently available or under development for use in HD hybrid electric vehicles (HEVs) involve different environmental considerations vis-à-vis potential releases of component materials. Examples include advanced lead acid (PbA), conventional nickel cadmium (NiCd) and nickel metal hydride (NiMH), and sodium nickel chloride (NaNiCl) batteries, and multiple options are emerging for lighter and higher capacity lithium ion (Li-ion) batteries. These battery types encompass a broad range of potential battery chemistries with diverse performance, safety, and toxicity tradeoffs.

During the life cycle of batteries, the potential exists for resource extraction, production, manufacturing, and disposal to generate waste, which would contribute to air pollution and landfill waste. This waste varies according to the material composition of the battery. Resource extraction related to the production of electric motors (the mining of rare earth metals, for example) could also lead to air pollution, water quality degradation, and other impacts. Although effective techniques to recycle electric vehicle batteries have been developed, electric battery recycling rates are still relatively low, in part because few electric batteries have reached the end of their life. In addition, it is currently cheaper to mine for new lithium than to extract it from used batteries.

7.1.2 Environmental Consequences

The projected reduction in fuel production and combustion resulting from the Final Action and alternatives (*see* Section 3.4 for projected fuel consumption and savings) could lead to a reduction in petroleum extraction and refining for the transportation sector. Waste produced during the petroleum refining process is released primarily into the air (75 percent of total waste) and water (24 percent of total waste) (EPA 1995). 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 1995). EPA reports that nine of the 10 most common toxic substances released by the petroleum refining industry are volatile chemicals (i.e., highly reactive substances that are prone to state changes or combustion, including benzene, toluene, ethylbenzene, xylene, cyclohexane, ethylbenzene, and 1,2,4-trimethylbenzene) (EPA 1995). These substances are present in crude oil and finished petroleum products. Other potentially dangerous substances that are commonly released during the refining process include ammonia, gasoline additives (methanol, ethanol, and methyl tert-butyl ether), chemical feedstocks (propylene, ethylene, and naphthalene) (EPA 1995), benzene, toluene, ethylbenzene, xylene, and n-hexane (EPA 2011).[2] Spent

[2] Ammonia is a form of nitrogen and can contribute to eutrophication (the process by which an aquatic ecosystem becomes enriched in nitrates or phosphates that help stimulate the growth of plant life, resulting in the depletion of dissolved oxygen) in surface water bodies. Once present in a surface water body, SO_x and NO_x can cause acidification of the water body, changing the pH of the system and affecting the function of freshwater ecosystems. Plants and animals in a given ecosystem are highly interdependent; therefore, changes in pH or aluminum levels can severely affect biodiversity (EPA 2008). As lakes and streams become more acidic, the numbers and types of fish as well as aquatic plants and animals in these water bodies could decrease. Benzene exposure could cause eye and skin irritation over the short term as well as blood disorders, reproductive and developmental disorders, and cancer (EPA 2011). Exposure to toluene emissions over the long term could cause nervous system effects, skin and eye irritation, dizziness, headaches, difficulty sleeping, and birth defects (EPA 2011). Short-term exposure to ethylbenzene emissions could cause throat and eye irritation, chest pain and pressure, and dizziness; long-term

sulfuric acid is by far the most commonly produced toxic substance; it is generally reclaimed, however, rather than being released or transferred for disposal (EPA 1995).

Spills of oil or other hazardous materials during oil and gas extraction and refining can also lead to surface- and groundwater contamination and result in impacts on drinking water and marine and freshwater ecosystems. As the Final Action has the potential to reduce overall petroleum extraction and refining levels due to increased fuel efficiency, it also has the potential to lower the overall number of hazardous material spills that result from extraction and refining.

Several of the VOCs emitted through oil and gas extraction and refining contribute to ground-level ozone and smog and are known or suspected carcinogens (EPA 2011). Many others are known to cause respiratory problems and impair the function of internal organs, particularly the liver and kidneys (EPA 2011). (*See* Chapter 4 for more information on air pollutants and quality.) Because of the decrease in oil and gas extraction and refining expected to occur under the Final Action, associated emissions of VOCs and these other potentially dangerous substances are expected to decrease as well.

Oil exploration and extraction also result in intrusions into onshore and offshore natural habitats and can involve construction within natural habitats. There are serious environmental concerns regarding ecosystems that experience encroachment and the effects of drilling on benthic (bottom-dwelling) populations, migratory bird populations, and marine mammals (Borasin et al. 2002). The decrease in oil and gas extraction and refining expected to occur under the Final Action is also likely to result in a decrease in these types of impacts to natural habitats.

Acid deposition associated with the release of SO_X and NO_X affects forest ecosystems negatively, both directly and indirectly. Potential impacts include stunted tree growth and increased mortality, primarily due to the leaching of soil nutrients (EPA 2012a). Declines in the biodiversity of aquatic species and changes in terrestrial habitats have most likely had ripple effects on wildlife species that depend on these resources. Acid deposition contributes to the eutrophication of aquatic systems, which can ultimately result in the death of fish and aquatic animals (Lindberg 2007). Damage from acid deposition 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 resulting from the Final Action could reduce pollutant emissions that cause acid deposition.

HD vehicles and equipment, as well as businesses engaged in the manufacture and assembly of HD vehicles, produce hazardous materials and toxic substances. EPA reports that solvents (xylene, methyl ethyl ketone, acetone, etc.) are the most commonly released toxic substances of those that the agency tracks for this industry (EPA 1995). These solvents are used to clean metal and are also used in the vehicle finishing process during assembly and painting (EPA 1995). Other industry waste includes metal paint and component-part scrap. Physical contact with solvents can present health hazards such as toxicity to the nervous system, reproductive damage, liver and kidney damage, respiratory impairment, cancer, and dermatitis (OSHA 2016).

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exposure could cause blood disorders (EPA 2011). Short-term exposure to xylene emissions could cause nose, eye, throat, and gastric irritation; nausea; vomiting; and neurological effects. Long-term exposure could affect the nervous system (EPA 2011). Short-term exposure to n-hexane emissions could cause dizziness, nausea, and headaches, and long-term exposure could cause numbness in extremities, muscular weakness, blurred vision, headaches, and fatigue (EPA 2011).

To comply with the final standards, manufacturers could incorporate a number of technologies for electrification, including HEVs, electrified accessories, fully electric power trains, electrified power take-off units, plug-in HEVs, external-power-to-electric-power trains for zero-emissions vehicle corridors, and alternative fuel/hybrid combinations (NRC 2014). Most current HEVs use nickel-metal-hydride or sodium-nickel-chloride batteries, but the trend for the near future for all HD electric vehicles is a shift toward Li-ion batteries (Majeau-Bettez et al. 2011). The Li-ion battery is the preferred battery technology because it is composed of lightweight materials, has comparatively low maintenance requirements, is able to stay charged longer, and meets the specific power and energy requirements of HD vehicles (Notter et al. 2010, Lee et al. 2011). *See* Chapter 6 for further details.

The final standards could induce increases in production and the use of electrochemical batteries for HD HEVs.[3] For instance, battery-powered Auxiliary Power Unit (APU) and Battery Air Conditioning (BAC) systems are idle control technologies that store electricity in batteries to provide accessory power and/or cooling to the truck when stationary. Some versions of waste heat recovery systems generate electricity to charge a high-voltage battery, which in turn, is used to drive a hybrid powertrain system. Stop-start or mild-hybrid technologies may necessitate an increase in the size of the battery or induce a switch to a higher capacity battery technology. All electric vehicles and many HEVs store energy in large battery systems to drive or supplement the power train. While Phase 2 discontinues the Phase 1 Advanced Technology Credits for hybrid power trains in favor of testing, it allows the Phase 1 credits to be carried over into Phase 2 for a period of 5 years. In this regard, Phase 2 may further incentivize HEV production for credit carry-over purposes. Because of the uncertainty surrounding which battery types and chemistries might be used by HD vehicles, NHTSA has not attempted to quantify the environmental impacts of increased battery production.

As mentioned previously, batteries such as those used in HEVs are considered universal waste by EPA under 40 CFR Part 273 and, therefore, can be collected under streamlined collection standards that facilitate environmentally sound collection and proper recycling and treatment. Life-cycle analysis of the material resource, energy intensiveness, and environmental issues associated with production, operation, and disposal of automotive batteries is an active area of research, especially regarding advanced Li-ion chemistries for HEVs and EVs. The production, use, and disposal of different types of electric batteries generate different types of waste. Both solid and hazardous waste are produced during the life cycle of the batteries, including during production and after their useful life in automobiles. Of the two main materials in electric batteries, nickel is classified as a hazardous air pollutant and hazardous waste, but lithium is not listed in either category (EPA 2010a, 40 CFR Part 261.33). The disposal of batteries can lead to adverse impacts because of the risk of toxic chemicals being released into the environment. At the end of the useful life of an EV or plug-in HEV, the battery will most likely not be fully exhausted and could be used for other purposes (EPA, NHTSA, and CARB 2010) to mitigate environmental impacts. When these batteries can no longer be reused, most of the materials can then be reprocessed and recycled. However, given the lack of battery recycling options at present, increased use of batteries in hybrid vehicles and auxiliary power or heating, ventilation, and air-conditioning (HVAC) units as a result of the Final Action could lead to increased waste from batteries. *See* Chapter 6 for further details.

All of the alternatives could lead to the increased use of some lighter weight materials and advanced technologies in HD vehicles, depending on the mix of methods the manufacturers use to meet the HD

[3] In addition to electrochemical batteries, other energy storage technologies, which were not considered here, could be applied to hybridize heavy-duty powertrains. Examples include ultracapacitors, high-speed flywheels, and hydraulic accumulators.

vehicle fuel efficiency standards, economic demands from consumers and other manufacturers, and technological developments. If manufacturers pursue vehicle mass reduction in response to the Phase 2 standards, a net increase in the waste stream could occur because of an increase in the amount of waste during the refining process related to the use of lighter weight materials in vehicle manufacturing, which would involve refining aluminum or manufacturing plastic (Schexnayder et al. 2001). Because there is still substantial uncertainty regarding how manufacturers would choose to comply with the standards, including whether they would use lighter weight materials, this EIS does not quantify effects related to waste produced during the refining process due to mass reduction.

In summary, the projected reduction in fuel production and consumption as a result of the Final Action could lead to a reduction in the amount of hazardous materials and waste created by the oil extraction and refining industries. NHTSA expects corresponding decreases in the associated environmental and health impacts of these substances. Increases in the electrification and hybridization of the HD vehicle fleet resulting from the Final Action, however, would increase the amount of waste from batteries as compared to the No Action Alternative. These effects could be mitigated by the expansion of battery repurposing, recycling, and reprocessing capabilities.

7.2 Historic and Cultural Resources

7.2.1 Affected Environment

Section 106 of the National Historic Preservation Act of 1966, codified in 2014 (54 U.S.C. 100101 et seq.), and its implementing regulations at 36 CFR Part 800 state that agencies of the Federal Government must take into account the impacts of their actions on historic properties. This process, known as the Section 106 process, is intended to support historic preservation and mitigate impacts on 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.[4]

NHTSA has no further obligations under the Section 106 process, in accordance with 36 CFR § 800.3(a)(1),[5] because the Final Action does not have the potential to cause impacts on historic properties. The analysis provided in Section 7.2.2 is not pursuant to the Section 106 process; rather it is intended to provide additional information in order to disclose impacts under NEPA.

7.2.2 Environmental Consequences

The corrosion of metals and the deterioration of paint and stone, which can reduce the cultural value of buildings, statues, cars, and other historically significant materials, can be caused by both acid rain and the

[4] 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; or have yielded, or may be likely to yield, information important in prehistory or history.

[5] "If the undertaking is a type of activity that does not have the potential to cause effects on historic properties, assuming such historic properties were present, the agency official has no further obligations under section 106 or this part." 36 CFR § 800.3(a)(1).

dry deposition of pollution (EPA 2012a). Deposition of dry acidic compounds found in acid rain can also dirty historic buildings and structures, causing visual impacts and increased maintenance costs (EPA 2012a). EPA established an Acid Rain Program under Title IV of the 1990 Clean Air Act Amendments in 1995 requiring major emissions reductions of SO_2 and NO_X from electric generating units (EPA 1995).

The projected reduction in fuel production and combustion as a result of the Final Action could lead to a reduction in the amount of pollutant emissions that cause acid deposition. 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 deposition. However, such effects are not quantifiable because of the inability to distinguish between acid deposition deterioration and natural weathering (rain, wind, temperature, and humidity) impacts on historic buildings and structures and the varying impact of a specific geographic location on any particular historical resource (Striegel et al. 2003).

All action alternatives are expected to result in fewer adverse impacts, including a reduction in acid deposition, as a result of the reduction in vehicle emissions compared with the No Action Alternative. Consequently, historic and cultural resources could be expected to benefit from reduced air quality and climate change impacts under the action alternatives.

7.3 Noise

7.3.1 Affected Environment

Vehicle noise is composed primarily of the interaction between the powertrain, tire/pavement, and vehicle aerodynamics. Vehicle aerodynamic noise levels are generally low at typical roadway speeds. The interaction between road surfaces and tires is the primary source of noise from trucks traveling on highways at high speeds (NAE 2010). Vehicle noise exposure can affect noise-sensitive receptors such as residents along roadways (environmental noise) as well as vehicle passengers. No recent studies have been conducted in the United States on the extent of highway traffic noise, but in 1981 EPA[6] estimated that 19.3 million people were exposed to Day-Night Average Sound Level (DNL) values of 65 decibels (dB). At 65 DNL, approximately 14 percent of people exposed to this noise level would be highly annoyed (ANSI S12.9-2005/Part 4). Traffic noise levels are greatly influenced by the vehicle fleet mix traveling over the highway or roadway. Based on Federal Highway Administration (FHWA) traffic noise measurements, noise levels for heavy trucks traveling at speeds of more than 50 miles per hour (mph) are between 80 and 90 dB (measured 50 feet from the vehicles), which are approximately 10 dB higher than noise levels for light vehicles at similar speeds (Fleming et al. 1996). Measured noise levels for medium trucks fall between those for light-duty and HD vehicles, averaging between 75 and 85 dB at speeds of more than 50 mph (Fleming et al. 1996).

The noise generated from air flowing over a vehicle, or wind noise, is directly related to the aerodynamics of a vehicle. For example, vertical exhaust pipes, “classic” or square frontal designs, and side mirrors all increase vehicle aerodynamic drag, thereby contributing to increased wind noise. The largest sources of wind noise for HD vehicles are the A-pillar[7] and mirrors of Class 8 combination tractors (National Research Council Canada 2012). To reduce wind noise, some vehicle features can be re-designed to lower

[6] “Noise Effects Handbook- A Desk Reference to Health and Welfare Effects of Noise” U.S. Environmental Protection Agency, July 1981.
[7] The A-pillars are the structures that hold either side of the windshield in place.

aerodynamic drag, in some cases by being incorporated into the interior of the vehicle (Jiang et al. 2011). This method of reducing wind noise by improving vehicle aerodynamics is referred to as aero-acoustics.

Noise from motor vehicles has been shown to be one of the primary causes of noise disturbance in homes (Theebe 2004, Ouis 2001). Excessive amounts of noise can present a disturbance and a hazard to human health at certain levels. Potential health hazards related to noise range from annoyance (sleep disturbance, lack of concentration, and stress) to hearing loss at high levels (Passchier-Vermeer and Passchier 2000). Primary sources of noise in the United States include road and rail traffic, air transportation, and occupational and industrial activities. Noise generated by vehicles causes inconvenience, irritation, and potentially even discomfort for occupants of other vehicles, pedestrians and other bystanders, and residents or occupants of surrounding property.

Wildlife exposure to chronic noise disturbances from motor vehicles can impair senses; change the habitat use, density, and occupancy patterns of species; increase stress response; modify pairing and reproduction; increase predation risk; and degrade communication (Barber et al. 2010, Bowles 1995, Larkin et al. 1996, Brown et al. 2013, Francis and Barber 2013). Although noise can affect wildlife, it does not mean the effect is always adverse. Wildlife species are exposed to many different noises in the environment and can adapt, and species differ in their level of sensitivity to noise exposure (Francis and Barber 2013). Even without human-generated noise, natural habitats have particular patterns of ambient noise resulting from, among other things, wind, animal and insect sounds, and noise-producing environmental factors, such as streams and waterfalls (California Department of Transportation 2007).

7.3.2 Environmental Consequences

Under all of the alternatives, NHTSA predicts that HD vehicle use would increase because of projected trends in VMT growth, resulting in potential increases in vehicle road noise. To comply with the final standards, however, manufacturers could reduce vehicle mass or increase the production of hybrid vehicles, which could lead to some reduction in the amount of environmental noise produced by motor vehicles. In general, noise levels from HD vehicles are location-specific, meaning that factors such as the time of day when increases in traffic occur, existing ambient noise levels, the presence or absence of noise abatement structures, and the location of schools, residences, and other sensitive noise receptors all influence whether there would be noise impacts. Location-specific analysis of noise impacts, however, is not possible given the available data. Instead, this section reports potential national-level changes in HD vehicle road noise resulting from the Final Action.

All of the action alternatives could lead to an increase in use of hybrid technologies, depending on the methods manufacturers use to meet the new requirements, economic demands from consumers and manufacturers, and technological developments. An increased percentage of hybrid technologies could result in reduced road noise, potentially offsetting some of the increase in road noise predicted to result from increased VMT. However, potential noise reductions achieved from an increase in the use of hybrid technologies could be offset at low speeds by manufacturer installation of pedestrian safety-alert sounds, as proposed by NHTSA (NHTSA 2013).

Because uncertainty is substantial regarding how manufacturers would choose to comply with the standards, including whether they would use hybrid technologies, this EIS does not quantify the effects related to noise due to hybridization of HD vehicles. A recent study on noise emissions of a hybrid electric mid-size truck (Class 2b or 3) showed that, in electric mode, the vehicle could produce an 8 dB noise benefit or greater at low speeds (under 30 mph) (Pallas et al. 2014). The use of low-rolling-resistance tires and single wide-base tires could also decrease the amount of exterior noise, vibration, and harshness from tire/road friction (EPA 2010b).

Although increases in VMT due to increased HD vehicle use could result in increased highway noise levels, the increased use of hybrid and electrified vehicles compared with the No Action Alternative could offset these increases in traffic-related noise. Overall, impacts to noise would depend on how vehicle manufacturers choose to comply with the regulations for MYs 2018 and beyond and which vehicle technologies are implemented.

7.4 Safety Impacts on Human Health

NHTSA analyzed how future improvements in fuel efficiency in the HD sector might affect human health and welfare. Both HD vehicle safety and the rate of traffic fatalities were considered. The analysis conducted by NHTSA for the MY 2017–2025 Final Rule found that reducing the weight of heavier light trucks but maintaining their size had a neutral impact on safety, thereby being unlikely to have an effect that would be large enough to be detected in a statistical analysis of crash data.

In the context of the current rulemaking for HD vehicle fuel efficiency and GHG emissions standards, one would expect that reducing the weight of HD vehicles would, if anything, have a positive impact on safety.[8] However, given the large difference in weight between light-duty vehicles and HD vehicles (especially HD vehicles with loads), the agencies expect that the impact of weight reductions for HD vehicles would have a negligible impact on safety for these classes of vehicles. The agencies recognize that conducting further study and research on the interaction of mass, size, and safety is important to assist future rulemaking, and NHTSA expects that ongoing collaborative interagency work to address this issue for the light-duty vehicle context might also inform the evaluation of safety effects for HD vehicles (NHTSA 2010a).

In a recent study, the Transportation Research Board examined HD vehicle crash trends using a crash rate index (CRI). The CRI, which was compared against baseline data, showed distinct differences among crash trends within the HD vehicle category (including both medium and heavy duty vehicles, as discussed in Chapter 1). The trend analysis showed that although crash rates for heavy duty vehicles are decreasing, the rate of this decline is slowed by contrary trends observed in medium duty vehicles (NAP 2015).

In 2015, NHTSA conducted a study on Heavy Truck Crashworthiness and potential countermeasures to improve occupant safety. The study estimated that the proportion of drivers killed in relation to the number of fatal truck crashes has remained between 14–16 percent over recent years. The study was based on data completed in 2003 and therefore represents model years 1995–2003. Manufacturers state that cab strength has improved significantly since that time. Several countermeasures were identified to help prevent and reduce future injuries, including increasing seat belt usage, increasing the integrity and robustness of cab structures, installation of side curtain air bags, and increasing occupant head space (NHTSA 2015).

Overall, while the action alternatives could result in fewer adverse impacts because of improvements in vehicle safety performance compared with the No Action Alternative, the specific impacts to vehicle safety depend on how vehicle manufacturers choose to comply with the standards for MYs 2018 and beyond and which vehicle technologies they implement.

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[8] Classes 7–8 vehicles may experience increases in the amount of freight hauled as a result of the Final Action, which would offset the vehicle mass reduction. However, HD vehicles (2b-3 and vocational) are expected to see a decrease in overall weight as a result of the Final Action.

7.5 Environmental Justice

Executive Order (EO) 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*,[9] 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 any disproportionately high and adverse human health or environmental effects that their actions might have on minority and low-income communities and provide opportunities for community input in the NEPA process. The Council on Environmental Quality (CEQ) has provided agencies with general guidance on how to meet the requirements of the EO as it relates to NEPA (CEQ 1997).

DOT Order 5610.2(a), *Department of Transportation Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*,[10] 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 or Latino, Asian American, American Indian or Alaskan Native, or Native Hawaiian or other Pacific islander. *Low-income* is defined as a person whose household income is at or below the Department of Health and Human Services poverty guidelines.

On August 4, 2011, the Secretary of Transportation, along with heads of other federal agencies, signed a Memorandum of Understanding on environmental justice and EO 12898, affirming the continued importance of identifying and addressing environmental justice considerations in agency programs, policies, and activities. As part of the Memorandum of Understanding, each federal agency agreed to review and update its existing environmental justice strategy as appropriate and publicize the updated strategy. Accordingly, DOT has reviewed and updated its environmental justice strategy to ensure that it continues to reflect its commitment to environmental justice principles and integrating those principles into DOT programs, policies, and activities (DOT 2014a). DOT also continues to provide annual implementation reports that detail specific actions and ongoing work to achieve environmental justice goals within the Department (DOT 2014b).

7.5.1 Affected Environment

The affected environment for this Final Action is nationwide, with a focus on areas that could contain low-income and minority communities and would be most likely to be exposed to the environmental and health effects of oil production, distribution, and consumption or the impacts of climate change. This includes areas where oil production and refining occur, areas in the vicinity of roadways, and urban areas that are subject to the heat island effect.[11]

There is evidence that proximity to oil refineries might be correlated with incidences of cancer and leukemia (Pukkala 1998, Chan et al. 2006, Bulka et al. 2013). 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, Wilker et al.

[9] *See* Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, 59 *Federal Register* 7629 (February 16, 1994).
[10] *See* Department of Transportation Updated Environmental Justice Order 5610.2(a), 77 *Federal Register* 27534 (May 10, 2012).
[11] The heat island effect refers to developed areas having higher temperatures than surrounding rural areas. *See* Section 5.5.1.5 for further discussion of the heat island effect.

2013, Hart et al. 2013). Climate change can affect overall global temperatures, which could, in turn, affect the number and severity of outbreaks of vector-borne illnesses (GCRP 2014). Chapter 3, Chapter 4, and Chapter 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.

Studies have found mixed evidence regarding whether there is a correlation between proximity to oil refineries and the prevalence 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 and minority populations to other types of industrial facilities (Mohai et al. 2009, 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 real estate market dynamics and migration after the facilities are sited (Pastor et al. 2001, Graham et al. 1999, Morello-Frosch 2002). 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.

It is also unclear whether there is a disproportionate prevalence of minority and low-income populations living near mobile sources of pollutants. Although there is some evidence that higher traffic levels depress property values and attract lower income populations, urban development can increase traffic on secondary roads and affect relatively expensive housing (O'Neill et al. 2005). 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). More recent studies have demonstrated a correlation between low-income and minority status and proximity to roadways at the national level. For example, Rowangould (2013) found that greater traffic volumes and densities at the national level are associated with larger shares of minority and low-income populations living in the vicinity. Similarly, Kingsley et al. (2014) found that schools with minority and underprivileged[12] children were disproportionately located within 250 meters of a major roadway.

Some of the areas that are most vulnerable to climate change tend to have a higher concentration of minority and low-income populations, potentially putting these communities at higher risk from climate variability and climate-related extreme weather events (GCRP 2014). For example, urban areas tend to have pronounced social inequities that could result in disproportionately larger minority and low-income populations than those in the surrounding non-urban areas (GCRP 2014). Urban areas are also subject to the most substantial temperature increases from climate change because of the urban heat island effect (Knowlton et al. 2007, GCRP 2014). Taken together, these tendencies demonstrate a potential for disproportionate impacts on minority and low-income populations in urban areas. Low-income populations in coastal urban areas, which are vulnerable to increases in flooding as a result of projected sea-level rise, larger storm surges, and human settlement in floodplains, could also be disproportionately affected by climate change because they are less likely to have the means to evacuate quickly in the event of a natural disaster and, therefore, are at greater risk of injury and loss of life (GCRP 2009, GCRP 2014).

[12] Public schools were determined to be predominantly "underprivileged" if they were eligible for Title I programs (federal programs that provide funds to school districts and schools with high numbers or high percentages of children who are disadvantaged) or had a majority of students who were eligible for free/reduced-price meals under the National School Lunch and Breakfast Programs.

Independent of proximity to sources of pollution or locations that would be disproportionately affected by climate change, low-income and minority populations might be more vulnerable to the health impacts of pollutants and climate change. The *2010 National Healthcare Disparities Report* stated that minority and low-income populations tend to have less access to health care services, and the services received are more likely to suffer with respect to quality (HHS 2003). Increases in heat-related morbidity and mortality as a result of higher overall and extreme temperatures are likely to affect minority and low-income populations disproportionately, partially as a result of limited access to air-conditioning and high energy costs (EPA 2009, O'Neill et al. 2005, GCRP 2014).

7.5.2 Environmental Consequences

The reduction in fuel production and consumption projected as a result of the Final Action could lead to a minor reduction in the amount of direct land disturbance resulting from oil exploration and extraction as well as a reduction in the amount of air pollution produced by oil refineries. To the extent that minority and low-income populations live in greater proximity to oil extraction, distribution, and refining facilities, they would be more likely to benefit from the Final Action, but as noted, there is mixed evidence regarding whether this is the case.

Under the action alternatives, emissions of most criteria and hazardous air pollutants are anticipated to decline compared to the No Action Alternative. However, as discussed in Chapter 4, the overall decrease in emissions predicted to occur as a result of the Final Action is not evenly distributed because of the increase in VMT from the rebound effect and regional changes in upstream emissions. Consequently, emissions of some criteria and hazardous air pollutants are predicted to increase in some air quality nonattainment areas in some years. Minority and low-income populations could be more vulnerable to the adverse consequences of these increases in hazardous air pollutants in certain nonattainment areas, as discussed in Section 7.5.1. Also, to the extent that minority and low-income populations live and travel in neighborhoods where there is a greater presence of older trucks (therefore a greater presence of vehicles that are not subject to the Final Action), they would be less affected by the changes in air quality that would result from the Final Action.

Because many of the changes in emissions are projected to be relatively small, no disproportionately high and adverse impacts on minority and low-income populations are expected. In terms of air quality in nonattainment areas where increases in some air pollutants are expected in some years, minority and low-income populations could be more vulnerable to these changes, as discussed in Section 7.5.1. In terms of climate, all action alternatives are expected to result in fewer adverse impacts as a result of climate change compared with the No Action Alternative. Consequently, minority and low-income populations could benefit from reduced climate change impacts under the action alternatives.

7.6 Unavoidable Adverse Impacts

As demonstrated in Chapters 3, 4, and 5, the more stringent HD vehicle fuel efficiency standards under each of the action alternatives are projected to result in a net decrease in energy consumption and a reduction in all criteria and hazardous air pollutant emissions compared with the No Action Alternative. Although increases in VMT under the action alternatives as compared to the No Action alternative are anticipated, these VMT increases will be offset by the increases in fuel efficiency associated with each action alternative, resulting in a net decrease in energy consumption and a net reduction in most pollutant emissions compared to the No Action Alternative.

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 GHG emissions in Earth's atmosphere. Neither the Final 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 with projected levels under the No Action Alternative, thereby diminishing anticipated climate change impacts. Nonetheless, climate impacts would be expected under all action alternatives.

Regarding air quality, most criteria and hazardous air pollutants would exhibit decreases in emissions under the action alternatives as compared to the No Action Alternative. Consequently, any adverse impacts on human health associated with these emissions are expected to be reduced, and no unavoidable adverse impacts from these emissions are anticipated. However, small increases in emissions of CO could occur under certain action alternatives and analysis years in some nonattainment areas because of increases in VMT (*see* Tables 4.2.1-4 and 4.2.2-4) . Despite these variations in pollutant emissions 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 efficiency across all alternatives compared with the No Action Alternative. Correspondingly, monetized health benefits are also anticipated to increase under all action alternatives.

7.7 Short-Term Uses and Long-Term Productivity

All of the action alternatives would result in a decrease in crude oil consumption and reduced GHG emissions (and associated climate change impacts) compared with the No Action Alternative. To meet the final fuel efficiency standards, manufacturers will need to apply various fuel-saving technologies during the production of HD vehicles. NHTSA cannot predict with certainty which specific technologies and techniques manufacturers would apply or in what order. Some HD 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 final standards will 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 final rule, consult the Final Rule and the Final Regulatory Impact Analysis.

7.8 Irreversible and Irretrievable Commitments of Resources

As noted above, some HD vehicle manufacturers might need to commit additional resources to existing, redeveloped, or new production facilities to meet the Phase 2 fuel efficiency 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 or other forms of energy) that manufacturers would expend in meeting the final 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 final Phase 2 HD standards would be at least partially offset by fuel savings generated from implementing the standards.

CHAPTER 8 MITIGATION

Council on Environmental Quality (CEQ) regulations implementing NEPA require that the discussion of alternatives in an environmental impact statement (EIS) "[i]nclude appropriate mitigation measures not already included in the proposed action or alternatives."[1] An EIS should discuss the "[m]eans to mitigate adverse environmental impacts."[2] As defined in the CEQ regulations, mitigation includes the following:[3]

- 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[4] but should analyze and consider all reasonable 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

Compared to Alternative 1 (No Action Alternative), each of the four action alternatives would reduce fuel consumption and greenhouse gas (GHG) emissions. As seen in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, the action alternatives would reduce the impacts of climate change that would otherwise occur under the No Action Alternative. According to the recent Fifth Assessment Report of the Intergovernmental Panel on Climate Change, substantial, sustained, and direct policy interventions around the world in the transportation sector can be consistent with long-term global carbon dioxide (CO_2) concentrations of 430 to 530 ppm. Moreover, a 15 to 40 percent reduction in global transportation-related CO_2 emissions by 2050 could be plausible compared to business as usual projections. However, there is limited evidence that reductions to date in carbon intensity, energy intensity, and activity have adequately constrained transportation sector GHG emissions growth in the context of mitigation targets. Stringent policy instruments and other incentives will be necessary to mitigate global increases in transportation emissions (Sims et al. 2014).

As reported in Chapter 4, *Air Quality*, emissions of most criteria and hazardous air pollutants would decrease under all action alternatives as compared to the No Action Alternative. Under the No Action

[1] 40 CFR § 1502.14(f)

[2] 40 CFR § 1502.16(h)

[3] 40 CFR § 1508.20

[4] *Northern Alaska Environmental Center v. Kempthorne*, 457 F.3d 969, 979 (citing *Robertson v. Methow Valley Citizens Counsel*, 490 U.S. 332, 352 (1989) (noting that NEPA does not contain a substantive requirement that a complete mitigation plan be actually formulated and adopted)). *See* also *Valley Community Preservation Comm'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).

Alternative, neither NHTSA nor EPA would issue a rule regarding heavy-duty (HD) vehicle fuel efficiency standards or GHG emissions for Phase 2 of the National Program. Compared to the No Action Alternative, health effects are estimated to be reduced and monetized health benefits would occur under all action alternatives for all analysis years (*see* Chapter 4, *Air Quality*). Although nationally most emissions are projected to decrease, some nonattainment areas within the United States could experience emissions increases for some pollutants under certain action alternatives and analysis years due to increases in vehicle miles traveled. These increases would represent a slight decline in the rate of reduction otherwise achieved by implementation of Clean Air Act (CAA) standards.

8.2 Mitigation Measures

NEPA does not obligate an agency to adopt a mitigation plan, but instead requires the agency to discuss and consider all reasonable measures that could be adopted. Because the action analyzed in this EIS primarily reduces the negative environmental consequences of fuel consumption and GHG emissions, and, therefore, comprises a type of mitigation measure in itself, the following discussion focuses on other federal actions that could also share the mitigation goals of the Final Action. These include current and future actions that NHTSA or other federal agencies could take to reduce increases in fuel consumption and GHG emissions in the transportation sector. As described in more detail below, many of these actions would provide even greater environmental benefits associated with the action alternatives. Although the measures described below are not being taken solely to address the impacts of the Final Action or action alternatives, NHTSA is describing them here because the actions could contribute to reducing adverse impacts or increasing net beneficial impacts of the Final Action and action alternatives.

As discussed above, some nonattainment areas could experience increases in some pollutant emissions as a result of implementation of the final standards. However, even if emissions in some nonattainment areas increase, the associated harm might not increase concomitantly. As described in Chapter 4, *Air Quality*, 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 (EPA 2014c). Also, vehicle and trailer manufacturers can choose which technologies to employ to reach the new HD fuel efficiency requirements. Some of their technology choices could result in higher or lower impacts for these emissions.

Each action alternative would reduce energy consumption and GHG emissions compared to the No Action Alternative, resulting in a net beneficial effect. Nonetheless, HD vehicles 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 that, together with the Final Action, will help reduce GHG and other emissions from the U.S. transportation sector. The programs discussed below are ongoing and at various stages of completion. All of the programs present the potential for future developments and advances that could further increase the net beneficial effect of the environmental impacts identified in this EIS.

Federal funds administered by the Federal Highway Administration (FHWA) are 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 could use for selected projects to reduce emissions (FHWA 2013). As state and local agencies conduct their review process and recognize the need to reduce emissions of CO, NO_x, particulate matter (PM) 2.5, acetaldehyde, acrolein, benzene, DPM, and formaldehyde (or other emissions eligible under the CMAQ Program, including the criteria pollutants and mobile source air toxics [MSATs] analyzed in this EIS), they can consider using CMAQ funds to help reduce these impacts.

Further, EPA has the authority to continue to improve vehicle emissions standards 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 2014e). In addition, in a joint NHTSA and EPA rulemaking published in September 2011, NHTSA and EPA established the Phase 1 HD National Program to improve fuel efficiency and reduce GHG emissions of HD vehicles.[5] The agencies estimated that the Phase 1 HD National Program standards will save approximately 530 million barrels of oil and reduce GHG emissions by approximately 270 million metric tons over the life of model years (MY) 2014–2018 vehicles.[6]

Similarly, in October 2012, NHTSA and EPA issued a joint final rule that established Corporate Average Fuel Economy (CAFE) and GHG emissions standards for MY 2017–2021 and MY 2017–2025 light-duty vehicle fleets, respectively.[7] This joint rulemaking is built on the May 2010 joint final rule in which NHTSA set CAFE standards and EPA set GHG emissions standards for MY 2012–2016 light-duty vehicles. The agencies estimate that the combination of these final standards will cut 6 billion metric tons of GHG emissions, save $1.7 trillion in fuel costs, and decrease the United States' dependence on oil by approximately 2 million barrels per day by 2025 (EPA 2014c). Final CAFE standards for MYs 2022–2025 will be established by NHTSA in a future rulemaking, based on the information available to the agency at that time.

EPA is also helping to reduce petroleum consumption and GHG emissions by implementing the Renewable Fuel Standards (RFS2) under CAA Section 211(o).[8] 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 it must ensure is consumed as motor vehicle fuel. RFS2, which went into effect July 1, 2010, increases the volume of renewable fuel required to be blended into gasoline from a baseline of 9 billion gallons in 2008 to 36 billion gallons by 2022.[9] EPA estimates that the greater volume of biofuel mandated by RFS2 will reduce life-cycle GHG emissions by an annual average of 138 million tons of carbon dioxide equivalent (CO_2e) in 2022 (EPA 2010). In November 2015, EPA finalized the renewable fuel standards to be 9.19, 9.52, and 10.10 percent for 2014, 2015, and 2016, respectively. EPA also finalized the biomass-based diesel volume requirements for 2017 (EPA 2015k). The percentage standard represents the ratio of renewable fuel volume to projected non-renewable gasoline and diesel volume. These standards are intended to

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[5] Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule, 76 FR 57106 (Sept. 15, 2011).

[6] *Id.*

[7] 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule, 77 FR 62624 (Oct. 15, 2012).

[8] 2014 Standards for Renewable Fuel Standard Program; Proposed Rule, 78 FR 71732 (Nov. 29, 2013).

[9] Final Rule: Regulations of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program. 75 FR 14670 (Mar. 26, 2010).

ensure "continued growth of renewable fuels while recognizing the practical limits on ethanol blending" (EPA 2013b).

EPA has also finalized standards of performance for allowable carbon emissions from new and existing power plants. In September 2013, EPA released a revised proposal that would cap emissions from new fossil fuel-fired electric utility generating units.[10] The final rule, announced in concurrence with the final Clean Power Plan by EPA and President Obama on August 3, 2015, established an emissions cap for new, modified, and reconstructed fossil fuel-fired electric utility steam generating units at 1,400 pounds of CO_2 per megawatt-hour of gross output (EPA 2015b). For existing power plants, EPA proposed the Clean Power Plan Rule in June 2014 requiring states to meet CO_2 emissions targets starting in 2020. The final Clean Power Plan Rule, issued on October 23, 2015, established the first-ever carbon standards for existing power plants to reduce CO_2 emissions by 32 percent below 2005 levels by 2030 (EPA 2015c).

Another example of EPA's efforts to reduce fuel consumption is the agency'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. Since 2004, SmartWay Partners report saving 120.7 million barrels of oil and eliminating 51.6 million metric tons of CO_2 (EPA 2014h). In 2015, EPA's SmartWay Technology Program finalized updates to its "trailer designation and trailer aerodynamic equipment verification programs" (EPA 2015l).

A comment on the Draft EIS (*see* Section 9.2) expressed concern about PM2.5 emissions from increased use of auxiliary power units (APUs) by Class 7–8 combination unit tractors. These vehicles are expected to use APUs to reduce extended idling of truck engines, and the engines powering APUs currently are required to meet less stringent PM emission standards than are truck engines. In its Final Rule, EPA is adopting a new PM emissions standard that applies exclusively to APUs. This standard will result in a lower increase in diesel PM emissions from APUs used on combination tractors than was projected in the Draft EIS. EPA expects that diesel particulate filters (DPFs) will be the usual control technology employed to meet this new standard.

Other potential idle control technologies are described in Section II of the Final Rule and include the following: fuel-operated heaters, battery-operated systems, thermal storage systems, and electrified parking spaces which may provide either an independent heating, cooling, and electrical power system or a power system that would allow the driver to plug in the tractor's on-board equipment. For further discussion of alternative technologies to reduce extended idling, *see* Section 6.3.7 of this EIS.

Further promoting efforts to reduce fuel consumption, the Federal Aviation Administration (FAA) is a sponsor of the Commercial Aviation Alternative Fuels Initiative (CAAFI), 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 FAA is working to incorporate the use of 1 billion gallons per year of renewable jet fuels that can be used in current aircraft engines without modification by 2018 (FAA 2014). CAAFI 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 also involved in a number of initiatives that aim to reduce fuel consumption. For example, DOE administers the Vehicle Technologies Program, which creates public-

[10] 79 FR 1429 (January 8, 2014).

private partnerships that enhance energy efficiency and productivity and bring clean technologies to the marketplace with the potential to reduce GHG emissions (DOE 2014a). DOE received $35.2 billion under the American Recovery and Reinvestment Act of 2009, and has invested in a variety of projects including state energy efficiency programs, smart grid development, breakthrough technologies, and energy efficiency upgrades for homeowners (C2ES 2013). On January 1, 2016, DOE announced over $58 million for vehicle technology advancement funding and published a report describing the successes of the Advanced Technology Vehicles Manufacturing Loan Program (DOE 2016c). 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 2009). Through these developments, the Clean Cities Program has saved over 7.5 billion gallons of oil since the start of the program in 1993 and prevented more than 6.8 million tons of GHG emissions in 2014 (DOE 2016d). DOE also oversees the Appliance and Equipment Standards Program, created under the National Appliance Energy Conservation Act of 1986, which establishes minimum efficiency standards for many household appliances. Since its inception, the program has implemented standards for more than 50 products, which represent about 90 percent of home energy use, 60 percent of commercial building use, and 29 percent of industrial energy use. Annual CO_2 savings will reach over 265 million tons of CO_2 by 2020 and the program will have cumulatively avoided 7 billion tons by 2030 (DOE 2016e).

The U.S. DOE has also invested $115 million to fund the development of a Class 8 "SuperTruck," intended to increase fuel efficiency in HD vehicles through improvements in aerodynamics, rolling resistance, engine efficiency, waste heat recovery, and engine idling technologies. To date, the SuperTruck teams have been very successful at meeting or exceeding the goals set forth by the SuperTruck initiative with suites of technologies that have the potential for achieving market success. A number of SuperTruck technologies are already making market inroads, particularly in the areas of aerodynamics and engine/drivetrain integration. Three of the four SuperTruck teams have already completed their SuperTruck projects, with Cummins/Peterbilt demonstrating a freight efficiency improvement of 86 percent, exceeding the 50 percent target of the initiative. Daimler has demonstrated a freight efficiency improvement of 115 percent in on-road vehicle testing over a 5-day, 312-mile round trip, and Volvo recently demonstrated an 88 percent freight efficiency improvement. All three teams were also successful at meeting the engine 50 percent brake thermal efficiency goal. The remaining team comprising Navistar and various partners, and they recently announced they expect to exceed the SuperTruck freight efficiency goal while also meeting the engine efficiency goal. While only 4 percent of on-road vehicles are commercial trucks (class 8 vehicles included), they use 20 percent of the total fuel consumed and are responsible for transporting 80 percent of goods in the United States (DOE 2014c). DOE administers additional programs that provide mitigating effects, such as the Section 1605b Voluntary Reporting of Greenhouse Gases, which facilitates information sharing by providing a forum for recording strategies and reductions in GHGs (DOE 2002). Such programs can provide a source of information and strategy for future programs. In January 2016, the Office of Energy Efficiency and Renewable Energy published the 2016–2020 Strategic Plan and Implementing Framework. This document is the blueprint that will guide the nation's progression in the global clean energy economy (DOE 2016f).

The U.S. Department of Transportation (DOT) Federal Railroad Administration's high-speed rail initiative intends to provide a travel alternative to reduce U.S. GHG emissions (FRA 2014). The overall strategy involves two parts: improving existing rail lines to make current train service faster and identifying potential corridors for the creation of high-speed rail. The American Recovery and Reinvestment Act of

2009 and annual appropriations have provided approximately $10 billion to expand the high-speed rail network in 33 states and the District of Columbia (SPRC 2011). DOT is also one of more than a dozen agency members of the U.S. Climate Change Technology Program, led by DOE, which aims to advance climate science, reduce GHG emissions, and promote international cooperation (DOE 2006, 2009).

Government-wide, Executive Order (EO) 13514 set measurable environmental performance goals for federal agencies and focused on making improvements in their environmental, energy, and economic performance. On January 29, 2010, President Obama announced that the Federal Government would reduce its GHG emissions from direct sources (e.g., lighting, heating, vehicle fuel, and federal projects) by 28 percent by 2020 (White House 2010a). This federal target was 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 2010b). As part of this executive order, federal agencies were required to submit annual GHG emissions inventories. For fiscal year (FY) 2012, the Federal Government reported 60 million metric tons of CO_2e of GHG emissions subject to the reduction target, which is a reduction of 9 million metric tons of CO_2e from the FY 2008 baseline (DOE 2014d). In 2012, CEQ published an updated *Federal Greenhouse Gas Accounting and Reporting Guidance* providing agencies with revised "inventory reporting requirements and calculation methodologies" (CEQ 2012). The Federal Government is the single largest energy consumer in the U.S. economy, and the White House estimated that achieving the federal agency GHG emissions reduction targets would result in a cumulative reduction of 101 million metric tons of CO_2 emissions (White House 2010a).

On March 19, 2015, President Obama issued EO 13693, which sets additional environmental performance goals for federal agencies and focuses on reducing GHG emissions, improving environmental performance and federal sustainability, and increasing efficiency. EO 13693 promotes the use of clean energy (such as renewable electric energy), building and water use efficiency and management, and improved agency motor vehicle fleet efficiency and management.

8.3 Conclusion

Emissions of most criteria and hazardous air pollutants are anticipated to decline under all action alternatives as compared to the No Action Alternative. Energy consumption and GHG emissions would also be reduced under all action alternatives as compared to the No Action Alternative. Several federal programs are in place to help increase the net beneficial impacts of the Final Action and alternatives. The initiatives and programs discussed in this chapter illustrate an existing and continuing trend of United States and global awareness, emphasis, and efforts toward reducing increases in energy consumption, GHG emissions, and other vehicle pollutants and mitigating their related environmental impacts.

CHAPTER 9 RESPONSES TO PUBLIC COMMENTS

On June 26, 2015, EPA's Notice of Availability of the Draft EIS appeared in the *Federal Register*.[1] In accordance with CEQ NEPA implementing regulations, this Notice of Availability triggered a public comment period that NHTSA set to end on August 31, 2015. Publication of the proposed rule opened a 60-day comment period, and the public was invited to submit comments on or before September 17, 2015, by posting to either the NHTSA or EPA docket (NHTSA-2014-0132 or EPA–HQ–OAR–2014–0827). The comment period for the Draft EIS and proposed rule was later extended to October 1, 2015.[2] NHTSA mailed approximately 1,100 letters notifying interested parties of the availability of the Draft EIS. As listed in Chapter 10 of the Draft EIS, these parties included federal, state, and local officials and agencies; elected officials; environmental and public interest groups; Native American tribes; and other interested individuals.

NHTSA and EPA also held public hearings on the Draft EIS and proposed rule on August 6, 2015, in Chicago, Illinois, and on August 18, 2015, in Long Beach, California. Transcripts from the public hearings and written comments submitted to NHTSA at the hearings are part of the administrative record and are available in the public docket. The testimonies and comments submitted during these hearings were relevant to the Notice of Proposed Rulemaking (NPRM) and Regulatory Impact Analysis (RIA) and not the Draft EIS and therefore were not included for further review in the Final EIS.

In preparing this Final EIS, NHTSA reviewed the 15 public submissions received in EIS Docket No. NHTSA-2014-0074, along with comments relevant to the EIS submitted to the NPRM and RIA dockets (NHTSA-2014-0132 and EPA–HQ–OAR–2014–0827). In this chapter of the Final EIS, NHTSA has quoted the comments that directly address themselves to specific aspects of the EIS and provided responses, as required by NEPA (40 CFR § 1503.4). The agency updated the EIS in response to comments on the proposed rule and Draft EIS and as a result of updated information that became available after the agency issued the Draft EIS.

Those comments submitted to both the NHTSA and EPA dockets that were not substantive to specific aspects of the EIS were approached as follows:

- The agencies received a number of comments directly addressing or otherwise related to the proposed rule under the rulemaking dockets (NHTSA-2014-0132 and EPA–HQ–OAR–2014–0827) and the EIS docket (NHTSA-2014-0074). This included comments regarding specific technologies, economic impacts of the rule, and harmonization of the agencies' rules. NHTSA has reviewed all of the comments, but only includes and addresses those comments considered substantive to the EIS in this chapter. NHTSA addresses comments that concern the rule but that are not substantive to the EIS in the Final Rule and its associated documents in the public docket.
- The agencies received oral and written comments stating either general support for or general opposition to the proposed rule. NHTSA appreciates those comments and has reviewed all of them, but because they do not raise specific, substantive issues or concerns pertaining to the EIS, this chapter does not respond to them directly. Instead, this chapter responds to comments specific to the EIS or that substantively addressed EIS analytical methods or approaches.

[1] 80 FR 36803 (June 26, 2015). The Draft EIS was posted to the NHTSA EIS docket (Docket No. NHTSA-2014-0074) on June 19, 2015.
[2] 80 FR 53756 (Sept. 8, 2015).

Table 9-1 lists the topics addressed in this chapter. Sections 9.1 through 9.7 provide relevant comments on the Draft EIS and the proposed rule, along with NHTSA's responses to those comments.

Table 9-1. Outline of Topics Raised in Public Comments on the Draft EIS

Number	Topic
9.1	Air Quality
9.2	Greenhouse Gas Emissions and Climate Change
9.3	Life-Cycle Impact Assessment of Vehicle Energy, Materials, and Technologies
9.4	Cultural Resources
9.5	Mitigation
9.6	Highway Trust Fund

9.1 Air Quality

Comments

Docket Number: NHTSA-2014-0074-0039
Commenter: Richard W. Corey, State of California Air Resources Board

ARB staff has reviewed NHTSA's Draft EIS and, in general, is supportive of its findings. However, we believe the EIS is lacking adequate discussion of one significant negative environmental impact projected from the Phase 2 standards, as well as discussion of any mitigation of that potential impact.

The U.S. Environmental Protection Agency (U.S. EPA) projects approximately a 10 percent increase in tailpipe emissions of toxic diesel particulate matter (PM) due to the increased use of auxiliary power units (APU) during extended idle operation resulting from the proposed Phase 2 standards (Table 111-2, Phase 2 Notice of Proposed Rulemaking (NPRM). In reviewing the Draft EIS, we were surprised to find no mention of the increased diesel PM emissions from APUs as a result of Phase 2 compliance. Although the NPRM projects that the diesel PM increases will be somewhat mitigated by upstream decreases in PM emissions, decreases in upstream emissions (from refining, transportation of fuel, etc.) will occur in different locations than the anticipated emission increases and hence will do little to mitigate or offset the health risk posed by increased tailpipe emissions. The anticipated increases in diesel PM from APU use are avoidable if U.S. EPA were to take regulatory action by adopting requirements already in place in California.

The Draft EIS does acknowledge that Phase 2 will increase APU use and discusses general environmental impacts from APU applications (e.g., the decrease of carbon dioxide and oxides of nitrogen emissions compared to when the truck engine is idling, upstream impacts such as extraction, fuel production, manufacturing, and transportation of APUs). However, we believe the EIS incorrectly claims that the use of APUs will decrease PM emissions. The life cycle analysis for APUs cited in the Draft EIS relies on outdated estimates based on sulfur levels in fuel that are no longer legal and that are inconsistent with today's truck technology (Draft EIS, page. 6-29) and hence presents erroneous conclusions. Specifically, the Gaines and Brodrick Hartman (2009) study cited used sulfur fuel with 500 parts per million (ppm) sulfur. Such 500 ppm sulfur fuel is incompatible with the use of diesel particulate filters (DPF), which have been required on all new heavy-duty trucks since the 2007 model year. The current allowable sulfur level for diesel fuel is 15 ppm, which enables use of DPFs. As correctly acknowledged in the U.S. EPA's NPRM, use of APUs will significantly increase, not decrease, tailpipe diesel PM emission. We recommend revising the Draft EIS to remove the incorrect conclusions regarding APU's decreasing overall PM emissions and to add a discussion of the actual projected increases in such emissions.

* * * *

In 1998, ARB identified diesel PM as a toxic air contaminant. Numerous studies have shown diesel PM's adverse effects on human respiratory and cardiovascular systems and its contribution to increased morbidity and mortality. Further details regarding diesel PM health effects is available on ARB's website at http://www.arb.ca.gov/research/diesel/diesel-health.htm.

* * * *

The health risk posed by diesel PM is one of the largest public health problems tackled by ARB in recent decades, and even after an extensive control program including a series of air toxic control measures in California (see for example the mobile source measures listed at http://www.arb.ca.gov/toxics/atcm/atcm.htm), diesel PM remains responsible for 60 percent of the known risk for air contaminants. Hence, controlling diesel PM remains a huge priority for ARB.

The PM 2.5 increases projected for the Phase 2 regulation are very significant—an increase of 1,631 tons and 2,257 tons of nationwide PM 2.5 in 2035 and 2050, respectively. To put those emission increases in perspective, they are greater than the entire projected reductions of 1,058 tons statewide diesel PM in 2023 from ARB's Truck and Bus Regulation.

Docket Number: NHTSA-2014-0074-0051
Commenter: Yale Klat, IdleAir

Diesel APUs consume less fuel, but are generally unfiltered, and therefore generate substantially more emissions tied to respiratory ailments than the main engine. PM emissions from idling trucks are well documented and occur at locations with the greatest impact to human health – congregated on large truck stops where drivers spend the night. Surrounding neighborhoods that are most likely to permit truck stop siting are least likely to have adequate access to health care services.

Our site staff receives complaints that drivers report headaches from neighboring diesel APUs. We encourage additional research on the health impacts of drastically increasing the adoption rate of APUs.

Response

In its Final Rule, EPA is adopting a new PM emissions standard that applies exclusively to APUs. This standard will result in a lower increase in DPM emissions from APUs used on combination tractors than that which was projected in the Draft EIS. EPA expects that DPFs will be the usual control technology employed to meet this new standard. In response to this comment, NHTSA has added a discussion of potential measures to reduce APU emissions to Section 8.2 of the Final EIS. In addition, the life cycle analysis discussion of APUs in the Final EIS has been revised to address the inapplicability of the Gaines and Brodrick Hartman study's findings with regard to PM emissions in the United States (see Section 6.3.7).

NHTSA recognizes that increases in tailpipe and APU emissions would occur in different locations than the decreases in upstream emissions. Section 4.1.1 of the Draft EIS and this Final EIS discuss the potential impacts to human health from traffic-related pollutant emissions, including DPM (*see* Section 4.1.1.2.5 for a discussion of DPM health impacts specifically). Although a truly local analysis (i.e., at the individual roadway level) is impractical for a nationwide EIS, the regional emissions analysis provided in this EIS still provides valuable information for the decisionmaker and the public and includes a discussion of the limitations of the approach. In addition, full-scale photochemical modeling provides the needed spatial and temporal detail to more completely and accurately estimate changes in ambient pollutant levels and their associated impacts on human health and welfare. NHTSA conducted a photochemical modeling analysis for this Final EIS using the same methodology as was used in the CAFE standards Final EISs and the MY 2014-2018 HD Phase 1 Final EIS, as explained in the Draft EIS. That analysis is contained in Appendix D.

Comment

Docket Number: NHTSA-2014-0132-0091
Commenter: California Air Resources Board

CARB supports the inclusion of all quantifiable impacts of reductions in GHG and non-GHG pollutants. Specifically, CARB suggests the inclusion of ecosystem benefits from reduced non-GHG pollutants including those to crops as outlined in Murphy et al. (1999). Changes in fugitive emissions from altered driving patterns on paved roads may also impact agriculture and ecosystem health. These impacts should be included in the analysis to the extent that they can be quantified.

Response

In Section 4.2 of the Final EIS, NHTSA discusses the estimated changes in vehicle emissions resulting from the Final Action, and shows that total emissions (including fugitive PM2.5 and DPM) would generally decrease as a result of the action. The Murphy et al. (1999) study, "The Cost of Crop Damage Caused by Ozone Air Pollution from Motor Vehicles," cited in the above comment derived low and high estimates of changes in welfare due to a 10 percent reduction in motor vehicle-related emissions. In the study, the maximum value estimated for direct plus indirect emissions of VOCs and NO_X for heavy-duty diesel vehicles was $0.30 per kilogram in 1990 dollars. This value corresponds to approximately $438 per ton in 2012 dollars (the year used for monetized health benefits in the Draft EIS). In contrast, the monetized health benefits from PM-related human mortality and morbidity given in Table 4.1.2-3 of the Final EIS range from $7,000 per ton to $1,261,000 per ton depending on the specified study, discount rate, and year. On a dollars-per-ton basis, the benefits of reduced crop damage are thus very small compared to the benefits of reduced human mortality and morbidity, as analyzed in the Draft and Final EIS. Consequently, the benefits of reduced crop damage would have a negligible impact on the overall costs and benefits of the proposed standards or on the selection of an alternative from among those analyzed in the EIS.

The emissions changes due to the standards are expected to be relatively uniform (in percentage terms) geographically. The standards are not expected to change driving patterns in terms of route choice or other location- or trip-specific variables that could affect emissions. Consequently, NHTSA does not expect substantial impacts on agriculture and ecosystem health due to altered driving patterns on paved roads.

9.2 Greenhouse Gas Emissions and Climate Change

Comment

Docket Number: NHTSA-2014-0074-0041
Commenter: Patrick Michaels, Cato Institute

We applaud the NHTSA for doing what most other federal agencies are not wont to do that is, make a direct determination of the impact that this proposed regulation will have on the course of future climate change.

* * * *

That the climate impact of the regulation does not rise above the noise in the model (which must include natural variability) is indisputable proof that the impacts are undetectable and therefore unverifiable.

These findings from the NHTSA are directly in line with the result of similar calculations that we ourselves have performed and reported for virtually all new federal proposed regulations and the conclusions that directly follow our investigations that the impact of the these and other federal actions on the future evolution of the earth's climate at global, regional, or local scales, is, by any normative scientific evaluation measure, inconsequential and undetectable.

As a result, the entirety of the 187-page Chapter 5 "Greenhouse Gas Emissions and Climate Change" (including the use of the problematic social cost of carbon in Sections 5.3.2, 5.4.1.2, and 5.4.2.2) with the exception of those portions of Sections 5.3 and 5.4 where the global climate impact calculations themselves are described should be removed from this EIS as well as all references to these sections in the reminder of the report, for example, the Summary.

Minimally, it would suffice to remove all the extant text under Section 5.5 "Health, Societal, and Environmental Impacts of Climate Change" and, replace it with the word "None."

Based directly upon the findings reported in this NHTSA draft Environmental Impact Statement, we recommend that "mitigating climate change" be henceforth removed from the justification included in this and all federal actions that may result in lower greenhouse gas emissions. If "mitigating climate change" is the primary impetus behind the action, then the action should be withdrawn.

Response

Although Sections 5.3 and 5.4 of the Final EIS show small differences in climate effects (CO_2 concentration, temperature, sea-level rise, precipitation) when expressed in terms of climate endpoints (i.e., the results at the end of an analysis period), any given GHG emissions mitigation strategy when taken alone generally shows small relative impacts on a global scale. A suite of many GHG emissions reduction policies in many countries and environmental sectors would need to be implemented to mitigate climate change substantially. Nonetheless, EPCA does not limit NHTSA's duty under NEPA to consider the environmental impacts of its rule. This Final EIS reflects NHTSA's careful consideration of the environmental impacts of its action and a reasonable range of alternatives. NHTSA's analysis of the rule's effect on global climate conditions is not intended to downplay the effectiveness or importance of the regulatory options in reducing CO_2 emissions and global warming impacts, but to quantify these potential reductions in the proper context for climate change.

The impacts reported in Chapter 5 of the EIS reflect the best available science regarding climate change. NHTSA recognizes the importance of climate change and the necessity of taking action to avert GHG emissions. The agency is acting within its statutory authority to increase average fuel efficiency of HD vehicles and, in so doing, to reduce annual U.S. HD vehicle emissions of CO_2. The MY 2012–2016 CAFE standards, the MY 2014–2018 Phase 1 HD standards, the MY 2017–2025 CAFE standards, and the Final Action will significantly reduce the GHG emissions that cause climate change. While NHTSA's action alone does not produce sufficient CO_2 emissions reductions, it is one of several federal programs that, together, could make substantial contributions in averting levels of abrupt and severe climate change. To the degree that the action in this rulemaking reduces the rate of CO_2 emissions growth, the rule contributes to the general reduction or delay of reaching dangerous climate change. Addressing dangerous climate change requires a global effort, including CO_2-reduction initiatives beyond the scope of the current rulemaking. NHTSA recognizes the potential severity of the consequences and the desire for unified action to avert the possible impacts associated with abrupt climate change.

By limiting increases in CO_2 concentrations, the action alternatives contribute to reducing the impact of climate change across resources that would otherwise occur under the No Action Alternative. Reductions in climate effects relating to temperature, precipitation, and sea-level rise would reduce impacts on affected resources. However, the magnitude of the changes in climate effects that the alternatives would produce are too small to address quantitatively in terms of their impacts on the specific resources. Nonetheless, it is clear that these resources are likely to be beneficially affected to some degree by the reduced climate change impacts expected to result from the action alternatives. 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 and directionally consistent, and will contribute to reducing the risks associated with climate change from what they would otherwise be under the No Action Alternative. Although 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 qualitative discussion of the impacts of climate change on various resource sectors in Section 5.5 of the Draft and Final EIS.

9.3 Life-Cycle Impact Assessment Of Vehicle Energy, Materials, and Technologies

Comment

Docket Number: NHTSA-2014-0132-0091
Commenter: California Air Resources Board

CARB staff suggests including BEVs and FCEVs in the lifecycle analysis. Those technologies are extremely efficient at utilizing energy for motive power and the lifecycle results are compelling. GVWR are expected to produce significantly less GHG emissions than similar MY conventional diesel fueled trucks on a WTW basis.

Response

The Draft and Final EIS include a section addressing lifecycle impacts from hybrid vehicles and batteries (*see* Section 6.3.6). As noted in that section, an accounting of the life-cycle environmental impacts of BEVs and PHEVs includes upstream impacts from generating electricity. Chapter 6 of the MY 2017–2025 CAFE standards Final EIS included an extensive discussion of the lifecycle impacts of hybrid vehicles and batteries, and was incorporated by reference into the Draft and Final EIS. Grid electricity is not expected to account for a significant share of fuel use in HD vehicles, but HEVs are likely to be used in an increasing share of Classes 2b–6 pickups, vans, and vocational vehicles. Therefore, the life-cycle impact assessment included in Chapter 6 of the Draft and Final EIS focuses on materials and technologies associated with HEVs (many of which are also applied in BEVs and PHEVs).

Comment

Docket Number: NHTSA-2014-0074-0042
Commenter: John Emerson, Michelin North America

The NGWBS 445/5 0- and 455/55R22.5 tires were introduced to be direct replacements for the conventional long haul dual tire sets, e.g. 275/80 or 295/75R22.5, and the 11R22.5, respectively, and offer LRR advantages as defined by the EPA/DOT NPRM Phase 2 Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles- Phase 2.

* * * *

The draft EIS states "... the literature review did not identify HD vehicle LCA studies that examined impacts from other stages of the tire life cycle, including manufacturing, retreading, and end-of-life management specific to LRR and WBS tires...".

In terms of a life cycle analysis (LCA), see the attached summary chart from the Quantis 2013 Michelin Truck Tires Life Cycle Analysis Project.

Response

NHTSA has reviewed the summary table provided. While this table shows the potential for life cycle benefits, the commenter did not provide NHTSA with the complete analysis, and NHTSA has been unable to locate it through publicly available databases. As a result, NHTSA cannot verify the methodology, underlying assumptions, or results.

Comment

Docket Number: NHTSA-2014-0074-0048
Commenter: Larry Schafer, National Biodiesel Board

EPA and NHTSA Properly Focus on Tailpipe Emissions Rather than Lifecycle Emissions.

EPA and NHTSA are proposing that the Phase 2 standards apply exclusively at the vehicle tailpipe. 80 Fed. Reg. at 40,158-40,159. In other words, "compliance is based on vehicle fuel consumption and GHG emission reductions, and does not reflect any so-called lifecycle emission properties." *Id.* at 40,159. NBB agrees that the agencies should not seek to undertake a separate analysis of lifecycle emissions here. 77 Fed. Reg. at 62,823. Indeed, the lifecycle analysis utilized by EPA for the RFS cannot assess actual emissions and should not be applied here. [Footnote 13: In the RFS rulemaking, EPA rejected inclusion of a global rebound effect in assessing emissions. See EPA Response to Clean Air Taskforce, World Wildlife Fund, National Wildlife Federation, and Friends of the Earth's Petitions for Reconsideration of the Renewable Fuel Standards (RFS2) (2011), available at http://www2.epa.gov/sites/production/files/2015-08/documents/rfs-response-to-petitions-02-17-11.pdf. NBB believes such analysis is speculative and unnecessary in light of the GHG emission reductions and energy security goals of the proposal.]

Comments on the Draft Environmental Impact Statement.

Although the agencies do not focus on lifecycle GHG emissions, NHTSA does address lifecycle emissions of biodiesel in the Phase 2 Fuel Efficiency Standards for Medium- and Heavy- Duty Engines and Vehicles Draft EIS (DEIS) (NHTSA-2014-0074-0034 at 6-15 to 6-16). NHTSA appropriately recognizes that "[w]hen used as a fuel in on-road vehicles, biodiesel offers significant GHG emission advantages over conventional petroleum diesel." DEIS at 6-15. It also references a more recent study showing lifecycle emissions can be decreased by up to 52 percent when using biodiesel as a replacement for petroleum diesel, which is based on soybean oil. The DEIS also references, however, the potential for land use changes. NBB continues to dispute the inclusion of land use impacts in the analysis as there is still no real-world evidence that the increased production of biodiesel has resulted in significant land use changes and the modeling that has been used remains inappropriate for measuring actual emissions. Moreover, the U.S. remains a sink for GHG emissions regarding the land use sector. While NHTSA references an analysis by Searchinger, as NHTSA also recognizes, the Searchinger article was disputed by the Department of Energy and should not be considered as a valid scientific analysis. Indeed, there are numerous factors that influence decisions regarding land use, and it would be too speculative to attempt to identify what emissions can be attributed to biofuel production. Further, as noted above, the industry has increased use of waste feedstocks, which has greater GHG emissions reductions. In any event, even considering such impacts, EPA still found lifecycle GHG emission reductions compared to petroleum to be above 50 percent (and as high as 86 percent).

NBB also requests that NHTSA make certain corrections to the discussion on use of biodiesel blends in diesel equipment in the DEIS at 6-15. NBB agrees that vehicles on the road today are compatible with higher blends of biodiesel. No detrimental effects have been seen with blends up to B20. NBB disagrees, however, with the notion that engines are only "warrantied" (or not warrantied) for certain fuels. OEMs generally identify the fuels they recommend for use in the owner's manuals, but we believe this is unrelated to any warranties provided on the engines themselves. OEMs generally do not <u>warranty</u> fuel at all, no matter if that fuel is biodiesel, diesel, gasoline or otherwise. Rather, the OEMs only warrant the actual parts and workmanship of the vehicle or engine that they themselves produce, and they simply provide recommendations for the types of fuel, lubricants, etc. that are suggested for use in those vehicles. [Footnote 14: For example, Caterpillar states within its Commercial Diesel Engine Fluids Recommendations that: "When auxiliary devices, accessories or consumables (filters, oil, additives, catalysts, fuel, etc.) made by other manufacturers are used on Caterpillar products, the Caterpillar warranty is not affected simply because of such use. Failures that result from the installation or usage of other manufacturers auxiliary devices, accessories or consumables, however, are not Caterpillar factory defects and therefore are NOT covered by Caterpillar's warranty."]

In addition, NHTSA states that "[b]iodiesel performance improves in cold temperatures as the blend is reduced." DEIS at 6-15. But, additional measures taken by the industry such as cold-flow additives, blending with #1 diesel fuel, and heated tanks/lines have demonstrated the ability to use blends up to B20 even in the coldest months and regions of the country.

Response

All references cited in the comment have been reviewed as part of the Final EIS analyses. Chapter 3 of the Final EIS discusses impacts on energy security, and the Affected Environment section of that chapter reflects the role of biodiesel and other renewable fuels in vehicle fuel use. NHTSA agrees that a complete lifecycle analysis of the impacts of this rulemaking is beyond the scope of this EIS. However, Chapter 6 of the Final EIS includes a literature synthesis of existing credible scientific information relevant to evaluating the potential environmental impacts from some of the fuels, materials, and technologies that may be used to comply with the Final Action and alternatives. This assessment helps inform the decisionmaker and the public about potential environmental impacts of the action.

The commenter expresses that it would be too speculative to attempt to identify what emissions from indirect land use change can be attributed to biofuel production. NHTSA acknowledges that there are differing conclusions reached in the scientific literature over the topic of indirect land use change emissions from biofuels production. Given these findings, it is important to acknowledge this topic and note two such examples of differing findings (i.e., Searchinger et al. 2008 and the U.S. Department of Energy) rather than exclude any discussion of potential indirect land use change emissions from biofuels. This discussion is included in Section 6.2.3.3 of the Final EIS.

The commenter also requested that NHTSA revise the discussion on use of biodiesel blends in diesel equipment as it pertains to manufacturer warranties. NHTSA acknowledges that use of biodiesel concentrations above 5 percent will not necessarily impact the manufacturer's warranty for the diesel equipment, depending upon the terms of that warranty. As a result, NHTSA has revised the life cycle analysis discussion of biodiesel in the Final EIS to remove the reference to warranties (*see* Section 6.2.3.1).

The commenter also suggested that NHTSA acknowledge that additional measures can allow for use of biodiesel blends up to B20 in cold weather conditions. NHTSA has revised the life cycle analysis discussion of biodiesel in the Final EIS to acknowledge the benefits of these measures (*see* Section 6.2.3.1).

9.4 Cultural Resources

Comment

Docket Number: NHTSA-2014-0074-0040
Commenter: Gene Whitehouse, United Auburn Indian Community of the Auburn Rancheria

We would like to receive copies of any archaeological reports that are completed for the project in order to ascertain whether or not the project could affect cultural resources that may be of importance to the UAIC. We also request copies of future environmental documents for the proposed project so that we have the opportunity to comment on potential impacts and proposed mitigation measures related to cultural resources. The information gathered will provide us with a better understanding of the project and cultural resources on site and is invaluable for consultation purposes. Finally, please contact us if you know of any Native American cultural resources within your project area or if you discover any.

Response

The current action does not involve any ground-disturbing activities, nor does it involve construction or land use, and is therefore unlikely to impact archeological or cultural resources. As a result, NHTSA did not complete any archeological reports specific to the Phase 2 standards. However, NHTSA will continue to provide the United Auburn Indian Community of the Auburn Rancheria and all federally recognized tribes with this Final EIS and copies of environmental documents for future actions that the Agency undertakes, as appropriate.

9.5 Mitigation

Comment

Docket Number: NHTSA-2014-0074-0039
Commenter: Richard W. Corey, State of California Air Resources Board

Because the Draft EIS did not mention the projected increase in tailpipe diesel PM emissions, it also did not include a discussion of mitigating measures in response to this issue in the chapter on mitigation, Chapter 8. We recommend that a discussion on such mitigation should be added. ARB staff believes mitigation should consist of requiring DPFs on APUs nationally. Further information regarding the California requirement for DPFs on APUs is available at http://www.arb.ca.gov/msprog/cabcomfort/cabcomfort.htm and title 13 California Code of Regulations 2485.

Response

In its Final Rule, EPA is adopting a new PM emissions standard that applies exclusively to APUs. This standard will result in a lower increase in DPM emissions from APUs used on combination tractors than was projected in the Draft EIS. EPA expects that DPFs will be the usual control technology employed to meet this new standard. Also, NHTSA has added a discussion of potential measures to reduce APU emissions to Section 8.2 of the Final EIS.

9.6 Highway Trust Fund

Comment

Docket Number: NHTSA-2014-0074-0037
Commenter: Kirk T. Steudle, Michigan Department of Transportation

MDOT supports the aim of the initiative to improve air quality and enhance the country's energy security.

MDOT also appreciates your review and consideration of the comments submitted in response to the issuance of the Notice of Intent to prepare the EIS, and respects your decision not to address concerns in the Draft EIS about the impact of the proposed regulations on the sustainability of transportation funding. However, MDOT respectfully disagrees with the characterization of the impacts on the Federal Highway Trust Fund as "highly speculative" (page 1-17 of the Draft EIS). While the overall impact on the environment from reduced transportation revenue that results from this initiative may be difficult to pin down with precision, the impact on transportation revenue and network demand is not.

The Draft Regulatory Impact Analysis, dated June 2015, estimates the impacts on transportation revenue and network demand. Reduced consumption of motor fuel is projected to reduce revenue from fuel sales by an aggregate total of $11.2 billion by the year 2029 (undiscounted – table 7-32 of the Draft Regulatory Impact Analysis). This represents a loss of revenue not only to the Federal Highway Trust Fund, but to all 50 states since every state relies, to some degree, on taxes levied on motor fuel to support investments in transportation infrastructure.

In addition to the loss of revenue for transportation investments, the analysis also projects that by the year 2029 vehicle miles traveled will increase by 5.7 billion miles (tables 7-60, 7-61, 7-62 of the Draft Regulatory Impact Analysis). This represents a significant increase in the demands placed on the highway network even as state and local governments most assuredly will continue to struggle in the face of stagnating or declining resources.

It is also worth noting that this rulemaking initiative is the fourth in a series of rulemakings aimed at increasing fuel efficiency of passenger, light-duty, medium-duty, and heavy-duty vehicles. Each rulemaking has a similar impact in undermining the continued viability of motor fuel taxes, an important and widely used method for generating revenue for improvements to our nation's transportation system, while increasing the demands placed on the system.

The Draft EIS represents a thorough analysis of the non-revenue implications of the proposed rulemaking and MDOT has no additional comments on the document. However, as this process moves forward, MDOT urges the United States Department of Transportation (USDOT) to take a more comprehensive approach to transportation and environmental policy. MDOT further urges USDOT to work closely with stakeholders to identify solutions to the long-term challenges related to the sustainability of the motor fuel tax as the primary source for revenue needed to maintain and improve our transportation network.

Response

As noted by the commenter, NHTSA addresses potential implications of the rulemaking on Highway Trust Fund revenue in the Regulatory Impact Analysis rather than in this EIS. The U.S. Department of Transportation recognizes the importance of stable, long-term sources of investment in transportation infrastructure, and it will continue to work closely with stakeholders and the Congress to ensure the continued solvency of the Trust Fund and longer term agreement on surface transportation funding that provides much-needed certainty for local and state governments and increases investment that addresses the country’s future needs.

CHAPTER 10 LIST OF PREPARERS AND REVIEWERS

10.1 U.S. Department of Transportation

Name/Role	Qualifications/Experience
PREPARERS	
James D. MacIsaac Jr., General Engineer, Contracting Officer's Representative, NHTSA (through early 2016)	
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	16 years of experience in project management, research, and environmental analysis in support of federal motor vehicle safety and fuel economy standards
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	32 years of experience in automotive engineering related to fuel economy and emissions development; 5 years of experience in vehicle fuel economy rulemaking

10.2 Consultant Team

ICF International supported the National Highway Traffic Safety Administration (NHTSA) in preparing its environmental analyses and this environmental impact statement (EIS).

Name/Role	Qualifications/Experience
PROJECT MANAGEMENT	
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	34 years of experience managing and preparing environmental, energy, and economic analyses
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11.1 Federal Agencies

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- Advisory Council on Historic Preservation, Office of Federal Programs
- Alaska Natural Gas Transportation Projects, Office of the Federal Coordinator
- Appalachian Regional Commission
- Appalachian Regional Commission, Program Operations Division
- Appalachian Regional Commission, Regional Planning and Research
- 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
- Department of Transportation, Federal Railroad Administration, Office of Policy and Development
- Executive Office of the President, Council on Environmental Quality
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- Federal Communications Commission, Wireless Telecommunications Bureau
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- Federal Energy Regulatory Commission, Division of Hydropower, Office of Energy Projects
- Federal Energy Regulatory Commission, Office of Energy Projects
- Federal Energy Regulatory Commission, Office of Pipeline Regulation
- Federal Maritime Commission
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- General Services Administration, Public Buildings Service
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- National Indian Gaming Commission, Contracts Division
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- Nuclear Regulatory Commission, Division of Intergovernmental Liaison and Rulemaking
- Oak Ridge National Laboratory
- Office of Management and Budget
- Overseas Private Investment Corporation, Environmental Affairs Department
- Presidio Trust, NEPA Compliance
- Securities and Exchange Commission, Office of General Counsel
- Securities and Exchange Commission, Office of Support Operations
- Small Business Administration, Facilities Management Branch
- Small Business Administration, Office of Administration
- Small Business Administration, Office of the General Counsel, Department of Litigation & Claims
- Social Security Administration, Office of Environmental Health and Occupational Safety
- Susquehanna River Basin Commission
- Tennessee Valley Authority, Environmental Policy and Planning
- 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, Rural Housing Service / Rural Business Cooperative 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, Gulf Coast Ecosystem Restoration Council
- U.S. Department of Commerce, National Marine Fisheries Service
- U.S. Department of Commerce, National Oceanic and Atmospheric Administration

- U.S. Department of Commerce, National Telecommunications and Information Administration
- U.S. Department of Commerce, NOAA National Marine Fisheries Service
- U.S. Department of Commerce, NOAA National Ocean Service
- U.S. Department of Defense, Army Corps of Engineers – Civil Works
- U.S. Department of Defense, Army Corps of Engineers Headquarters
- 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, U.S. Air Force Basing and Units
- U.S. Department of Defense, Department of Army, Office of the Assistant Secretary of the Army, Installations & Environment
- U.S. Department of Defense, Department of Navy, Office of the Deputy Assistant Secretary of the Navy (Environment)
- U.S. Department of Defense, Joint Guam Program Office
- U.S. Department of Defense, National Guard Bureau
- U.S. Department of Defense, National Guard Bureau, Office of the Chief Counsel
- U.S. Department of Defense, Navy Installations Command
- U.S. Department of Defense, Office of Deputy Undersecretary Defense (Installations and Environment)
- U.S. Department of Defense, Office of the Assistance Chief of Staff for Installations
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- U.S. Department of Energy, Office of the General Counsel – Office of NEPA Policy and Compliance
- U.S. Department of Energy, Western Area Power Administration
- U.S. Department of Health and Human Services, Center for Tobacco Products, Toxicology and Environmental Science
- U.S. Department of Health and Human Services, Centers for Disease Control and Prevention
- U.S. Department of Health and Human Services, Centers for Disease Control and Prevention – National Center for Environmental Health
- 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 Food Safety and Applied Nutrition
- 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, 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
- 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 Homeland Security
- 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, 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
- U.S. Department of Homeland Security, Immigration and Customs Enforcement
- U.S. Department of Homeland Security, U.S. Citizen and Immigration Services, Facilities Management Division
- U.S. Department of Homeland Security, U.S. Customs and Border Protection
- U.S. Department of Housing and Urban Development, Office of Environment and Energy
- 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
- U.S. Department of Interior, Bureau of Reclamation, 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
- U.S. Department of Interior, U.S. Fish and Wildlife Service
- U.S. Department of Interior, U.S. Geological Survey – Environmental Management Branch
- U.S. Department of Interior, Bureau of Safety and Environmental Enforcement
- U.S. Department of Interior, National Park Service, Environmental Quality Division
- U.S. Department of Interior, Office of Environmental Affairs, Natural Resources Management
- 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
- 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
- U.S. Department of Justice, National Institute of Justice
- U.S. Department of Justice, Office of Justice Programs, Office of General Counsel
- U.S. Department of Justice, U.S. Marshals Service, 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 and Variances
- U.S. Department of Labor, Occupational Safety and Health Administration, Office of Regulatory Analysis
- U.S. Department of Labor, Office of the Assistant Secretary for Policy
- U.S. Department of State, Bureau of Oceans and International Environmental and Scientific Affairs
- 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, OES/EQT
- U.S. Department of the Treasury, Office of Environment, Safety, and Health
- U.S. Department of Transportation
- U.S. Department of Transportation, Federal Highway Administration, Office of Project Development and Environmental Review
- U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Office of the Chief Counsel
- 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, Saint Lawrence Seaway Development Corporation
- U.S. Department of Transportation, Surface Transportation Board, Office of Environmental Analysis
- U.S. Department of Transportation, Federal Aviation Administration
- U.S. Department of Transportation, Federal Highway Administration
- U.S. Department of Transportation, Federal Transit Administration, Office of Human and Natural Environment
- U.S. Department of Transportation, Maritime Administration
- U.S. Department of Transportation, Office of Assistant Secretary for Transportation Policy
- U.S. Department of Transportation, Office of General Counsel
- U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration
- U.S. Department of Transportation, Volpe Center
- U.S. Department of Treasury, CDFI Fund, Office of Legal Counsel
- U.S. Department of Veterans Affairs, Veterans Health Administration, Office of General Counsel
- U.S. Department of Veterans Affairs, Veterans Health Administration
- U.S. Environmental Protection Agency

- U.S. Institute for Environmental Conflict Resolution
- United States Agency for International Development
- United States Postal Service
- 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
- California Air Resources Board
- Connecticut Department of Environmental Protection
- Delaware Office of Management and Budget, Budget Development, Planning & Administration
- 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 Department of Planning
- Maryland Department of Transportation
- Maryland State Clearinghouse for Intergovernmental Assistance
- Massachusetts Office of the Attorney General
- Michigan Department of Transportation
- Minnesota Department of Commerce, Division of Energy Resources
- Minnesota Department of Environmental Protection
- Nevada Division of State Lands
- New Hampshire Office of Energy and Planning, Attn: Intergovernmental Review Process
- North Dakota Department of Commerce
- Pennsylvania Department of Environmental Protection
- Puerto Rico Highway and Transportation Authority
- Puerto Rico Planning Board, Federal Proposals Review Office
- Rhode Island Division of Planning
- Saint Thomas, VI Office of Management and Budget
- South Carolina Office of State Budget
- Southeast Michigan Council of Governments
- The Governor of Kentucky'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 Bill Walker, Governor of Alaska
- The Honorable Lolo Matalasi Moliga, Governor of American Samoa
- The Honorable Doug Ducey, Governor of Arizona
- The Honorable Asa Hutchinson, Governor of Arkansas
- The Honorable Jerry Brown, Governor of California
- The Honorable John Hickenlooper, Governor of Colorado
- The Honorable Dannel 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 David Ige, Governor of Hawaii
- The Honorable C.L. "Butch" Otter, Governor of Idaho
- The Honorable Bruce Rauner, Governor of Illinois
- The Honorable Mike Pence, Governor of Indiana
- The Honorable Terry Branstad, Governor of Iowa
- The Honorable Sam Brownback, Governor of Kansas
- The Honorable Matt Bevin, Governor of Kentucky
- The Honorable John Bel Edwards, Governor of Louisiana
- The Honorable Paul LePage, Governor of Maine
- The Honorable Larry Hogan, Governor of Maryland
- The Honorable Charles Baker, Governor of Massachusetts
- The Honorable Rick Snyder, Governor of Michigan
- The Honorable Mark Dayton, Governor of Minnesota
- The Honorable Phil Bryant, Governor of Mississippi
- The Honorable Jeremiah (Jay) Nixon, Governor of Missouri
- The Honorable Steve Bullock, Governor of Montana
- The Honorable Pete Ricketts, Governor of Nebraska
- The Honorable Brian Sandoval, Governor of Nevada
- The Honorable Maggie Hassan, 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 Pat McCrory, Governor of North Carolina
- The Honorable Jack Dalrymple, Governor of North Dakota
- The Honorable Ralph Deleon Guerrero Torres, Governor of the Commonwealth of the Northern Mariana Islands

- The Honorable John Kasich, Governor of Ohio
- The Honorable Mary Fallin, Governor of Oklahoma
- The Honorable Kate Brown, Governor of Oregon
- The Honorable Tom Wolf, Governor of Pennsylvania
- The Honorable Alejandro García Padilla, Governor of Puerto Rico
- The Honorable Gina Raimondo, 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 Greg Abbott, Governor of Texas
- The Honorable Kenneth Mapp, Governor of the United States Virgin Islands
- The Honorable Gary Herbert, Governor of Utah
- The Honorable Peter Shumlin, Governor of Vermont
- The Honorable Terry McAuliffe, Governor of Virginia
- The Honorable Jay Inslee, 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 Muriel Bowser, Mayor of the District of Columbia

11.4 Federally Recognized Native American Tribes

- Absentee-Shawnee Tribe of Indians of Oklahoma
- Agdaagux Tribe of King Cove
- Agua Caliente Band of Cahuilla Indians of the Agua Caliente Indian Reservation, California
- Ak-Chin Indian Community of the Maricopa (Ak Chin) Indian Reservation, Arizona
- Akiachak Native Community
- Akiak Native Community
- Alabama-Coushatta Tribes of Texas
- Alabama-Quassarte Tribal Town
- Alatna Village
- Algaaciq Native Village (St. Mary's)
- Allakaket Village
- Alturas Indian Rancheria, CA
- Alutiiq Tribe of Old Harbor
- Angoon Community Association
- Anvik Village
- Apache Tribe of Oklahoma
- Arctic Village
- Aroostook Band of Micmacs
- Asa'carsarmiut Tribe

- Assiniboine & Sioux Tribes of the Fort Peck Indian Reservation, MT
- Atqasuk Village (Atkasook)
- Augustine Band of Cahuilla Indians, California
- Bad River Band of Lake Superior Tribe of Chippewa Indians
- Bay Mills Indian Community, Michigan
- Bear River Band of the Rohnerville Rancheria, California
- Beaver Village
- Berry Creek Rancheria of Maidu Indians of California
- Big Lagoon Rancheria, California
- Big Pine Paiute Tribe of the Owens Valley
- Big Sandy Rancheria of Western Mono Indians of California
- Big Valley Band of Pomo Indians of the Big Valley Rancheria, California
- Birch Creek Tribe
- Bishop Paiute Tribe
- Blackfeet Tribe of the Blackfeet Indian Reservation of MT
- Blue Lake Rancheria, California
- Bridgeport Indian Colony
- Buena Vista Rancheria of Me-wuk Indians of California
- Burns Paiute Tribe
- Cabazon Band of Mission Indians, California
- Cachil DeHe Band of Wintun Indians of the Colusa Indian Community of the Colusa Rancheria, California
- Caddo Nation of Oklahoma
- Cahto Tribe of the Laytonville Rancheria
- Cahuilla Band of Mission Indians of the Cahuilla Reservation, California
- California Valley Miwok Tribe, California
- Campo Band of Diegueno Mission Indians of the Campo Indian Reservation, California
- Capitan Grande Band of Diegueno Mission Indians of California (Barona Group of Capitan Grande Band of Mission Indians of the Barona Reservation, California)
- Capitan Grande Band of Diegueno Mission Indians of California: Viejas (Barona Long) Group of Capitan Grande Band of Mission Indians of the Viejas Reservation, California
- Catawba Indian Nation
- Cayuga Nation
- Cedarville Rancheria, California
- Central Council of the Tlingit & Haida Indian Tribes of Alaska
- Chalkyitsik Village
- Cheesh-Na Tribe
- Chemehuevi Indian Tribe of the Chemehuevi Reservation, California
- Cher-Ae Heights Indian Community of the Trinidad Rancheria, California
- Cherokee Nation
- Chevak Native Village

- Cheyenne and Arapaho Tribes, Oklahoma
- Cheyenne River Sioux Tribe of the Cheyenne River Reservation, SD
- Chickaloon Native Village
- Chicken Ranch Rancheria of Me-wuk Indians of California
- Chignik Bay Tribal Council
- Chignik Lake Village
- Chilkat Indian Village (Klukwan)
- Chilkoot Indian Association (Haines)
- Chinik Eskimo Community (Golovin)
- Chippewa Cree Indians of the Rocky Boy's Reservation, MT
- Chitimacha Tribe of Louisiana
- Chuloonawick Native Village
- Circle Native Community
- Citizen Potawatomi Nation (Oklahoma)
- Cloverdale Rancheria of Pomo Indians of California
- Cocopah Tribe of Arizona
- Coeur D'Alene Tribe
- Cold Springs Rancheria of Mono Indians of California
- Colorado River Indian Tribes of the Colorado Indian Reservation, Arizona and California
- Comanche Nation, Oklahoma
- 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 of Oregon
- Coquille Indian Tribe
- Coushatta Tribe of Louisiana
- Cow Creek Band of Umpqua Tribe of Indians
- Cowlitz Indian Tribe
- Coyote Valley Band of Pomo Indians of California
- Craig Tribal Association
- Crow Creek Sioux Tribe of the Crow Creek Reservation, SD
- Crow Tribe of Montana
- Curyung Tribal Council
- Death Valley Timbi-sha Shoshone Tribe
- Delaware Nation, Oklahoma

- Delaware Tribe of Indians
- Douglas Indian Association
- Dry Creek Rancheria Band of Pomo Indians, California
- Duckwater Shoshone Tribe of the Duckwater Reservation, Nevada
- Eastern Band of Cherokee Indians
- Eastern Shawnee Tribe of Oklahoma
- Eastern Shoshone Tribe of the Wind River Reservation, Wyoming
- Egegik Village
- Eklutna Native Village
- Elem Indian Colony of Pomo Indians of the Sulphur Bank Rancheria, California
- Elk Valley Rancheria, California
- Ely Shoshone Tribe of Nevada
- Emmonak Village
- Enterprise Rancheria of Maidu Indians of California
- Evansville Village (aka Bettles Field)
- Ewiiaapaayp Band of Kumeyaay Indians, California
- Federated Indians of Graton Rancheria, California
- Flandreau Santee Sioux Tribe of South Dakota
- Forest County Potawatomi Community, Wisconsin
- Fort Belknap Indian Community
- Fort Bidwell Indian Community of the Fort Bidwell Reservation of California
- Fort Independence Indian Community of Paiute Indians of the Fort Independence Reservation, California
- Fort McDermitt Paiute and Shoshone Tribes of the Fort McDermitt Indian Reservation, Nevada and Oregon
- Fort McDowell Yavapai Nation, Arizona
- Fort Mojave Indian Tribe of Arizona, California & Nevada
- Fort Sill Apache Tribe of Oklahoma
- Galena Village (aka Louden Village)
- Gila River Indian Community of the Gila River Indian Reservation, Arizona
- Grand Traverse Band of Ottawa & Chippewa Indians, Michigan
- Greenville Rancheria
- Grindstone Indian Rancheria of Wintun-Wailaki Indians of California
- Guidiville Rancheria of California
- Gulkana Village
- Habematolel Pomo of Upper Lake, California
- Hannahville Indian Community, Michigan
- Havasupai Tribe of the Havasupai Reservation, Arizona
- Healy Lake Village
- Ho-Chunk Nation of Wisconsin
- Hoh Indian Tribe

- Holy Cross Village
- Hoonah Indian Association
- Hoopa Valley Tribe, California
- Hopi Tribe of Arizona
- Hopland Band of Pomo Indians, California
- Houlton Band of Maliseet Indians
- Hualapai Indian Tribe of the Hualapai Indian Reservation, Arizona
- Hughes Village
- Huslia Village
- Hydaburg Cooperative Association
- Igiugig Village
- Iipay Nation of Santa Ysabel, California
- Inaja Band of Diegueno Mission Indians of the Inaja and Cosmit Reservation, California
- Inupiat Community of the Arctic Slope
- Ione Band of Miwok Indians of California
- Iowa Tribe of Kansas & Nebraska
- Iowa Tribe of Oklahoma
- Iqurmiut Traditonal Council
- Ivanoff Bay Tribe
- Jackson Band of Miwuk Indians
- Jamestown S'Klallam Tribe
- Jamul Indian Village of California
- Jena Band of Choctaw Indians
- Jicarilla Apache Nation, New Mexico
- Kaguyak Village
- Kaibab Band of Paiute Indians of the Kaibab Indian Reservation, Arizona
- Kaktovik Village (aka Barter Island)
- Kalispel Indian Community of the Kalispel Reservation
- Karuk Tribe
- Kashia Band of Pomo Indians of the Stewarts Point Rancheria, California
- Kasigluk Traditional Elders Council
- Kaw Nation, Oklahoma
- Kenaitze Indian Tribe
- Ketchikan Indian Corporation
- Kewa Pueblo
- Keweenaw Bay Indian Community, Michigan
- 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

- King Salmon Tribe
- Kiowa Indian Tribe of Oklahoma
- Klamath Tribes
- Klawock Cooperative Association
- Kletsel Dehe Band of Wintun Indians
- Knik Tribe
- Koi Nation of Northern California
- Kokhanok Village
- Kootenai Tribe of Idaho
- Koyukuk Native Village
- La Jolla Band of Luiseno Indians, California
- La Posta Band of Diegueno Mission Indians of the La Posta Indian Reservation, California
- 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 of MI
- Las Vegas Tribe of Paiute Indians of the Las Vegas Indian Colony, Nevada
- Levelock Village
- Lime Village
- Little River Band of Ottawa Indians, Michigan
- Little Traverse Bay Bands of Odawa Indians, Michigan
- Lone Pine Paiute-Shoshone Tribe
- Los Coyotes Band of Cahuilla & Cupeno Indians, California
- Lovelock Paiute Tribe of the Lovelock Indian Colony, Nevada
- Lower Brule Sioux Tribe of the Lower Brule Reservation, SD
- Lower Elwha Tribal Community
- Lower Sioux Indian Community in the State of Minnesota
- Lummi Tribe of the Lummi Reservation
- Lytton Rancheria of California
- Makah Indian Tribe of the Makah Indian Reservation
- Manchester Band of Pomo Indians of the Manchester Rancheria, California
- Manley Hot Springs Village
- Manokotak Village
- Manzanita Band of Diegueno Mission Indians of the Manzanita Reservation, Califonria
- Mashantucket Pequot Indian Tribe
- Mashpee Wampanoag Tribe
- Match-e-be-nash-she-wish Band of Pottawatomi Indians of Michigan
- McGrath Native Village
- Mechoopda Indian Tribe of Chico Rancheria, California
- Menominee Indian Tribe of Wisconsin
- Mentasta Traditional Council
- Mesa Grande Band of Diegueno Mission Indians of the Mesa Grande Reservation, California

- Mescalero Apache Tribe
- Metlakatla Indian Community, Annette Island Reserve
- Miami Tribe of Oklahoma
- Miccosukee Tribe of Indians
- Middletown Rancheria of Pomo Indians of California
- Minnesota Chippewa Tribe
- Minnesota Chippewa Tribe - Bois Forte Band (Nett Lake)
- Minnesota Chippewa Tribe - Fond du Lac Band
- Minnesota Chippewa Tribe - Grand Portage Band
- Minnesota Chippewa Tribe - Leech Lake Band
- Minnesota Chippewa Tribe - Mille Lacs Band
- Minnesota Chippewa Tribe - White Earth Band
- Mississippi Band of Choctaw Indians
- Moapa Band of Paiute Indians of the Moapa River Indian Reservation, Nevada
- Mohegan Tribe of Indians of Connecticut
- Mooretown Rancheria of Maidu Indians of California
- Morongo Band of Mission Indians, California
- Muckleshoot Indian Tribe
- Naknek Native Village
- Narragansett Indian Tribe
- 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 Brevig Mission
- Native Village of Buckland
- Native Village of Cantwell
- Native Village of Chenega (aka Chanega)
- Native Village of Chignik Lagoon
- Native Village of Chitina
- Native Village of Chuathbaluk (Russian Mission, Kuskokwim)
- Native Village of Council
- Native Village of Deering
- Native Village of Diomede (aka Inalik)
- Native Village of Eagle
- Native Village of Eek
- Native Village of Ekuk

- Native Village of Ekwok
- Native Village of Elim
- Native Village of Eyak (Cordova)
- Native Village of False Pass
- Native Village of Fort Yukon
- Native Village of Gakona
- Native Village of Gambell
- Native Village of Georgetown
- Native Village of Goodnews Bay
- Native Village of Hamilton
- Native Village of Hooper Bay
- Native Village of Kanatak
- Native Village of Karluk
- Native Village of Kiana
- Native Village of Kipnuk
- Native Village of Kivalina
- Native Village of Kluti-Kaah (aka Copper Center)
- Native Village of Kobuk
- Native Village of Kongiganak
- Native Village of Kotzebue
- Native Village of Koyuk
- Native Village of Kwigillingok
- Native Village of Kwinhagak (aka Quinhagak)
- Native Village of Larsen Bay
- Native Village of Marshall (aka Fortuna Ledge)
- Native Village of Mary's Igloo
- Native Village of Mekoryuk
- Native Village of Minto
- Native Village of Nanwalek (aka English Bay)
- Native Village of Napaimute
- Native Village of Napakiak
- Native Village of Napaskiak
- Native Village of Nelson Lagoon
- Native Village of Nightmute
- Native Village of Nikolski
- Native Village of Noatak
- Native Village of Nuiqsut (aka Nooiksut)
- Native Village of Nunam Iqua
- Native Village of Nunapitchuk
- Native Village of Ouzinkie
- Native Village of Paimiut

- Native Village of Perryville
- Native Village of Pilot Point
- Native Village of Pitka's Point
- Native Village of Point Hope
- Native Village of Point Lay
- Native Village of Port Graham
- Native Village of Port Heiden
- Native Village of Port Lions
- Native Village of Ruby
- Native Village of Saint Michael
- Native Village of Savoonga
- Native Village of Scammon Bay
- Native Village of Selawik
- Native Village of Shaktoolik
- Native Village of Shishmaref
- Native Village of Shungnak
- Native Village of Stevens
- Native Village of Tanacross
- Native Village of Tanana
- Native Village of Tatitlek
- Native Village of Tazlina
- Native Village of Teller
- Native Village of Tetlin
- Native Village of Tuntutuliak
- Native Village of Tununak
- Native Village of Tyonek
- Native Village of Unalakleet
- Native Village of Unga
- Native Village of Venetie Tribal Government
- Native Village of Wales
- Native Village of White Mountain
- Navajo Nation, Arizona, New Mexico & Utah
- Nenana Native Association
- New Koliganek Village Council
- New Stuyahok Village
- Newhalen Village
- Newtok Village
- Nez Perce Tribe
- Nikolai Village
- Ninilchik Village
- Nisqually Indian Tribe

- Nome Eskimo Community
- Nondalton Village
- Nooksack Indian Tribe
- Noorvik Native Community
- Northern Arapaho Tribe of the Wind River Reservation, Wyoming
- Northern Cheyenne Tribe
- Northfork Rancheria of Mono Indians of California
- Northway Village
- Northwestern Band of Shoshone Nation
- Nottawaseppi Huron Band of the Potawatomi, MI
- Nulato Village
- Nunakauyarmiut Tribe
- Oglala Sioux Tribe
- Ohkay Owingeh
- Omaha Tribe of Nebraska
- Oneida Nation
- Oneida Nation of New York
- Onondaga Nation
- Organized Village of Grayling (aka Holikachuk)
- Organized Village of Kake
- Organized Village of Kasaan
- Organized Village of Kwethluk
- Organized Village of Saxman
- Orutsararmiut Traditional Native Council
- Oscarville Traditional Village
- Otoe-Missouria Tribe of Indians, Oklahoma
- Ottawa Tribe of Oklahoma
- Paiute Indian Tribe of Utah (Cedar Band of Paiutes, Kanosh Band of Paiutes, Koosharem Band of Paiutes, Indian Peaks Band of Paiutes, and Shivwits Band of Paiutes)
- Paiute-Shoshone Tribe of the Fallon Reservation and Colony, Nevada
- Pala Band of Mission Indians
- Pamunkey Indian Tribe
- Pascua Yaqui Tribe of Arizona
- Paskenta Band of Nomlaki Indians of California
- Passamaquoddy Tribe - Indian Township
- Passamaquoddy Tribe - Pleasant Point
- Pauloff Harbor Village
- Pauma Band of Luiseno Mission Indians of the Pauma & Yuima Reservation, California
- Pawnee Nation of Oklahoma
- Pechanga Band of Luiseno Mission Indians of the Pechanga Reservation, California
- Pedro Bay Village

- Penobscot Nation
- Peoria Tribe of Indians of Oklahoma
- Petersburg Indian Association
- Picayune Rancheria of Chukchansi Indians of California
- Pilot Station Traditional Village
- Pinoleville Pomo Nation, California
- Pit River Tribe, California
- Platinum Traditional Village
- Poarch Band of Creeks
- Pokagon Band of Potawatomi Indians, Michigan & Indiana
- Ponca Tribe of Indians of Oklahoma
- Ponca Tribe of Nebraska
- Port Gamble S'Klallam Tribe
- Portage Creek Village (aka Ohgsenakale)
- Potter Valley Tribe, California
- Prairie Band of Potawatomi Nation
- Prairie Island Indian Community in the State of MN
- 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 Taos
- Pueblo of Tesuque
- Pueblo of Zia
- Puyallup Tribe of the Puyallup Reservation
- Pyramid Lake Paiute Tribe of the Pyramid Lake Reservation, Nevada
- Qagan Tayagungin Tribe of Sand Point Village
- Qawalangin Tribe of Unalaska
- Quartz Valley Indian Community of the Quartz Valley Reservation of California
- Quechan Tribe of the Fort Yuma Indian Reservation, California & Arizona
- Quileute Tribe of the Quileute Reservation
- Quinault Indian Nation

- Ramah Navajo Chapter
- Ramona Band of Cahuilla, California
- Rampart Village
- Red Cliff Band of Lake Superior Chippewa Indians of Wisconsin
- Red Lake Band of Chippewa Indians, Minnesota
- Redding Rancheria, California
- Redwood Valley or Little River Band of Pomo Indians of the Redwood Valley Rancheria California
- Reno-Sparks Indian Colony, Nevada
- Resighini Rancheria, California
- Rincon Band of Luiseno Mission Indians of the Rincon Reservation, California
- Robinson Rancheria Band of Pomo Indians, CA
- Rosebud Sioux Tribe of the Rosebud Indian Reservation, SD
- Round Valley Indian Tribes, Round Valley Reservation, California
- Sac & Fox Tribe of the Mississippi in Iowa
- Sac and Fox Nation of Missouri in Kansas and Nebraska
- Sac and Fox Nation, Oklahoma
- Saginaw Chippewa Indian Tribe of Michigan
- Saint George Island
- Saint Paul Island
- Saint Regis Mohawk Tribe
- Salt River Pima-Maricopa Indian Community of the Salt River Reservation, Arizona
- Samish Indian Nation
- San Carlos Apache Tribe of the San Carlos Reservation, Arizona
- San Juan Southern Paiute Tribe of Arizona
- San Manuel Band of Mission Indians, California
- San Pasqual Band of Diegueno Mission Indians of California
- Santa Rosa Band of Cahuilla Indians, California
- Santa Rosa Indian Community of the Santa Rosa Rancheria, California
- Santa Ynez Band of Chumash Mission Indians of the Santa Ynez Reservation, California
- Santee Sioux Nation, Nebraska
- Sauk-Suiattle Indian Tribe
- Sault Ste. Marie Tribe of Chippewa Indians, Michigan
- Scotts Valley Band of Pomo Indians of California
- Seldovia Village Tribe
- Seminole Tribe of Florida
- Seneca Nation of Indians
- Seneca-Cayuga Nation
- Shageluk Native Village
- Shakopee Mdewakanton Sioux Community of Minnesota
- Shawnee Tribe
- Sherwood Valley Rancheria of Pomo Indians of California

- Shingle Springs Band of Miwok Indians, Shingle Springs Rancheria (Verona Tract), California
- Shinnecock Indian Nation
- Shoalwater Bay Indian Tribe
- Shoshone-Bannock Tribes of the Fort Hall Reservation
- Shoshone-Paiute Tribes of the Duck Valley Reservation, Nevada
- Sisseton-Wahpeton Oyate of the Lake Traverse Reservation, SD
- Sitka Tribe of Alaska
- Skagway Village
- Skokomish Indian Tribe
- Skull Valley Band of Goshute Indians of Utah
- Snoqualmie Indian Tribe
- Soboba Band of Luiseno Indians, California
- Sokaogon Chippewa Community, Wisconsin
- South Naknek Village
- Southern Ute Indian Tribe
- Spirit Lake Tribe, North Dakota
- Spokane Tribe of the Spokane Reservation
- Squaxin Island Tribe of the Squaxin Island Reservation
- St. Croix Chippewa Indians of Wisconsin
- Standing Rock Sioux Tribe of North & South Dakota
- Stebbins Community Association
- Stillaguamish Tribe of Indians of Washington
- Stockbridge Munsee Community, Wisconsin
- Summit Lake Paiute Tribe of Nevada
- Sun'aq Tribe of Kodiak
- Suquamish Indian Tribe of the Port Madison Reservation
- Susanville Indian Rancheria, California
- Swinomish Indian Tribal Community
- Sycuan Band of the Kumeyaay Nation
- Table Mountain Rancheria of California
- Takotna Village
- Tangirnaq Native Village (aka Woody Island)
- Tejon Indian Tribe
- Telida Village
- Te-Moak Tribe of Western Shoshone Indians of Nevada (Four constituent bands: Battle Mountain Band; Elko Band; South Fork Band and Wells Band)
- The Chickasaw Nation
- The Choctaw Nation of Oklahoma
- The Modoc Tribe of Oklahoma
- The Muscogee (Creek) Nation
- The Osage Nation

- The Quapaw Tribe of Indians
- The Seminole Nation of Oklahoma
- Thlopthlocco Tribal Town
- Three Affiliated Tribes of the Fort Berthold Reservation, ND
- Tohono O'odham Nation of Arizona
- Tolowa Dee-Ni' Nation
- Tonawanda Band of Seneca
- Tonkawa Tribe of Indians of Oklahoma
- Tonto Apache Tribe of Arizona
- Torres Martinez Desert Cahuilla Indians, California
- Traditional Village of Togiak
- Tulalip Tribes of Washington
- Tule River Indian Tribe of the Tule River Reservation, California
- Tuluksak Native Community
- Tunica-Biloxi Indian Tribe
- Tuolumne Band of Me-Wuk Indians of the Tuolumne Rancheria of California
- Turtle Mountain Band of Chippewa Indians of North Dakota
- Tuscarora Nation
- Twenty-Nine Palms Band of Mission Indians of California
- Twin Hills Village
- Ugashik Village
- Umkumiut Native Village
- United Auburn Indian Community of the Auburn Rancheria of California
- United Keetoowah Band of Cherokee Indians in Oklahoma
- Upper Sioux Community, Minnesota
- Upper Skagit Indian Tribe
- Ute Indian Tribe of the Uintah & Ouray Reservation, Utah
- Ute Mountain Ute Tribe
- Utu Utu Gwaitu Paiute Tribe of the Benton Paiute Reservation, California
- Village of Alakanuk
- Village of Anaktuvuk Pass
- Village of Aniak
- Village of Atmautluak
- Village of Bill Moore's Slough
- Village of Chefornak
- Village of Clarks Point
- Village of Crooked Creek
- Village of Dot Lake
- Village of Iliamna
- Village of Kalskag
- Village of Kaltag

- Village of Kotlik
- Village of Lower Kalskag
- Village of Ohogamiut
- Village of Red Devil
- Village of Salamatoff
- Village of Sleetmute
- Village of Solomon
- Village of Stony River
- Village of Venetie
- Village of Wainwright
- Walker River Paiute Tribe of the Walker River Reservation, Nevada
- Wampanoag Tribe of Gay Head (Aquinnah)
- Washoe Tribe of Nevada & California (Carson Colony, Dresslerville Colony, Woodfords Community, Stewart Community, & Washoe Ranches)
- White Mountain Apache Tribe of the Fort Apache Reservation, Arizona
- Wichita and Affiliated Tribes
- Wilton Rancheria
- Winnebago Tribe of Nebraska
- Winnemucca Indian Colony of Nevada
- Wiyot Tribe, California
- Wrangell Cooperative Association
- Wyandotte Nation
- Yakutat Tlingit Tribe
- Yankton Sioux Tribe of South Dakota
- Yavapai-Apache Nation of the Camp Verde Indian Reservation, Arizona
- Yavapai-Prescott Indian Tribe
- Yerington Paiute Tribe of the Yerington Colony & Campbell Ranch, Nevada
- Yocha Dehe Wintun Nation, California
- Yomba Shoshone Tribe of the Yomba Reservation, Nevada
- Ysleta del Sur Pueblo
- Yupiit of Andreafski
- Yurok Tribe of the Yurok Reservation, California
- Zuni Tribe of the Zuni Reservation

11.5 Stakeholders

- AAA Mid-Atlantic, Public and Government Relations
- AirFlow Truck Company
- Alaska Public Interest Research Group
- Alliance of Automobile Manufacturers, Environmental Affairs
- Alliance of Idle Mitigation Technologies

- Alliance to Save Energy
- Allison Transmission
- Aluminum Association
- America's Natural Gas Alliance
- American Association of Blacks in Energy
- American Automotive Policy Council
- American Chemistry Council, Plastics
- American Council for an Energy-Efficient Economy
- American Council on Renewable Energy, Biomass Coordinating Council
- American Fuel & Petrochemical Manufacturers, Regulatory Affairs
- American Gas Association
- American Indian Science and Engineering Society
- American International Automobile Dealers Association
- American Iron and Steel Institute
- 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
- American Trucking Associations
- Appalachian Mountain Club
- Arizona Public Interest Research Group
- Association of International Automobile Manufacturers, Inc.
- Association of Metropolitan Planning Organizations
- Auto Research Center
- BAE Systems Platform Solutions
- BlueGreen Alliance
- BMW of North America, LLC
- Border Valley Trading LTD
- Boyden Gray & Associates PLLC
- Bridgestone Americas Tire Operations Product Development Group, Techincal Standards and Regulations
- California Air Pollution Control Officers Association
- CALPIRG (Public Interest Research Group)
- CALSTART
- CATERPILLAR
- Cato Institute
- Center for Auto Safety

- Center for Biological Diversity
- Center for Biological Diversity, Climate Law Institute
- Central States Air Resources Agencies
- Ceres and the Investor Network on Climate Risk (INCR)
- Chrysler Group LLC
- Citizens' Utility Board of Oregon
- Clean Air Task Force
- Clean Fuel Development Coalition
- Commission for Environmental Cooperation
- Competitive Enterprise Institute
- Con-way Inc
- 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
- Coulomb Technologies, Inc.
- Counteract Balancing Beads
- Criterion Economics, L.L.C.
- Crowell Moring
- Cummins, Inc.
- DAF Trucks
- Daimler AG
- Daimler Trucks North America
- Daimler Vans USA LLC
- Dale Kardos & Associates, Inc.
- Dallas Clean Energy LLC
- Dana Holding Corporation
- Defenders of Wildlife
- Democratic Processes Center
- Detriot Diesel Corporation
- Eaton Corp.
- Ecology Center
- Edison Electric Institute
- Electric Power Research Institute, Electric Transportation & Energy Storage
- Empire State Consumer Association
- Engine Manufacturers Association and Truck 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.
- Ford Motor Company
- Friends Committee on National Legislation
- Gary Dewyn
- General Motors
- Gibson, Dunn & Crutcher LLP
- Greater Washington Interfaith Power and Light c/o Interfaith Conference of Metropolitan Washington
- Green Truck Association (GTA)
- Growth Energy
- HayDay Farms, Inc
- HINO
- Honda North America, Inc.
- Honeywell Transportation Systems
- Hyundai Kia America Technical Center Inc. (HATCI)
- ICM
- IdleAir
- 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
- Jewish Community Relations Council
- Joint Trade Association
- Justice and Witness Ministries
- Kenworth Truck Company
- Kirkland & Ellis LLP
- Mack and Volvo Trucks
- Manufacturers of Emission Controls Asociation
- 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
- Mercatus Center, George Mason University
- Metro 4, Inc. – Southeastern States Air Resource Managers, Inc.
- Michelin North America, Inc.
- Michigan Tech University, ME-EM Department
- Mid-Atlantic Regional Air Management Association, Inc.
- Mitsubishi Motors North America, Inc.
- Motor & Equipment Manufacturers Association
- National Alliance of Forest Owners
- National Association of Attorneys General
- National Association of Clean Air Agencies
- 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 Biodiesel Board
- 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 Propane Gas Association, Regulatory Affairs
- National Ready Mixed Concrete Association (NRMCA)
- National Truck Equipment Association
- National Wildlife Federation, National Advocacy Center
- Natural Gas Vehicles (NGV) America
- Natural Resources Canada
- Natural Resources Defense Council
- Natural Resources Defense Council, Climate Center
- NAVISTAR Truck Group
- New Jersey Citizen Action
- New Mexico Public Interest Research Group

- Nissan North America, Inc.
- Northeast States for Coordinated Air Use Management
- Nose Cone Manufacturing Company
- NTEA – The Association for the Work Truck Industry
- NY Public Interest Research Group
- Odyne Systems
- Oshkosh Corporation
- Owner-Operator Independent Drivers Association
- Ozone Transport Commission
- PACCAR Inc.
- Peterbilt Motors Company
- Pew Environment Group, Climate and Energy Programs
- Pierobon & Partners
- Podesta GROUP
- Pollution Probe
- Porsche Cars North America, Inc.
- Presbyterian Church (USA)
- Public Citizen
- Recreation Vehicle Industry Association
- Renewable Fuels Association
- Republicans for Environmental Protection
- Richard Baron
- Road Safe America
- Rocky Mountain Institute
- Rubber Manufacturers Association
- Ryder System, Inc
- Saab Cars North America, Inc.
- Safe Climate Campaign
- Santa Clara Pueblo
- SaviCorp, Inc.
- School Bus Manufacturers Technical Council
- Securing America's Future Energy
- Sentech, Inc.
- Sierra Club
- Socially Responsible Investing, General Board of Pension and Health Benefits of The United Methodist Church
- Society of Plastics, Inc., Industry Affairs – Environment & Health
- Subaru of America
- SUN DAY Campaign

- Teamsters Joint Council 25
- Tesla Motors, Inc.
- 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 National RV Dealers Association (RVDA)
- The Pew Charitable Trusts, Pew Environment Group
- The Truman National Security Project
- The United Methodist Church General, Board of Church and Society
- Thor Motor Coach
- TIAX LLC
- ToChi Technologies Inc
- Toyota Motor North America, Inc.
- Trillium Asset Management Corporation
- Truck Manufacturer's Association
- Truck Trailer Manufacturers Association
- Trucking and Renting and Leasing Association
- Tufts University, The Fletcher School of Law and Diplomacy
- U.S. Chamber of Commerce
- U.S. Conference of Mayors
- U.S. Public Interest Research Group
- Union for Reform Judaism
- Union of Concerned Scientists
- Union of Concerned Scientists, Clean Vehicles Program
- 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
- United Steelworkers
- University of Colorado School of Law
- University of Michigan Center for Sustainable Systems
- University of Michigan Transportation Research Institute
- 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.
- Volvo Group North America
- Volvo Trucks North America
- Wabash National Corporation
- Waste Management
- Wayne Stewart Trucking Company
- West Virginia University
- Western Governors' Association
- Western Regional Air Partnership
- Western States Air Resources Council
- Wisconsin Consumers League
- World Auto Steel
- World Resources Institute, Greenhouse Gas Protocol Team

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