The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021–2026 Passenger Cars and Light Trucks

Draft Environmental Impact Statement

July 2018

Docket No. NHTSA-2017-0069

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

NHTSA
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Draft Environmental Impact Statement for the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Year 2021–2026 Passenger Cars and Light Trucks

Lead Agency

National Highway Traffic Safety Administration (NHTSA)

Cooperating Agencies

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

Overview

This Draft Environmental Impact Statement (Draft EIS) analyzes the environmental impacts of fuel economy standards and reasonable alternative standards for model years 2021 to 2026 for passenger cars and light trucks. NHTSA has proposed these new or amended Corporate Average Fuel Economy (CAFE) standards under the Energy Policy and Conservation Act of 1975, as amended by the Energy Independence and Security Act of 2007. Environmental impacts analyzed in this Draft EIS include those related to fuel and energy use, air quality, and climate change. In developing the proposed standards, NHTSA considered "technological feasibility, economic practicability, the effect of other vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy," as required by 49 U.S.C. § 32902(f).

Public Comment Period

EPA will publish a Notice of Availability of this Draft EIS in the *Federal Register*, which will include the date by which comments must be received. Additionally, NHTSA will publish the public comment period end date on its website at http://www.nhtsa.gov/fuel-economy. To submit comments electronically, go to http://www.regulations.gov and follow the online instructions for submitting comments. File comments in Docket No. NHTSA-2017-0069. If sending by mail, send an original and two copies of comments to Docket Management Facility, M-30, U.S. Department of Transportation, West Building, Ground Floor, Room W12-140, 1200 New Jersey Avenue, SE, Washington, DC 20590. You must reference Docket No. NHTSA-2017-0069. Comments may also be submitted by fax to (202) 493-2251. Any announcements about public hearings will be made available at http://www.nhtsa.gov/fuel-economy and in a *Federal Register* notice.

NHTSA will simultaneously issue the Final EIS and Record of Decision, pursuant to 49 U.S.C. § 304a(b) and U.S. Department of Transportation *Final Guidance on MAP-21 Section 1319 Accelerated Decisionmaking in Environmental Reviews* (https://www.transportation.gov/sites/dot.gov/files/docs/MAP-21_1319_Final_Guidance.pdf) unless it is determined that statutory criteria or practicability considerations preclude simultaneous issuance.

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Acronyms and Abbreviations

°C	degrees Celsius
μg/m^3	micrograms per cubic meter
AC	air conditioning
AEFs	average emission factors
AEO	Annual Energy Outlook
AFLEET	Alternative Fuel Life-Cycle Environmental and Economic Transportation
AKPIRG	Alaska Public Interest Research Group
AMOC	Atlantic Meridional Overturning Circulation
AOGCMs	atmospheric-ocean general circulation models
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
ASTM	American Society for Testing and Materials
BEVs	Battery electric vehicles
Btu	British thermal units
CAA	Clean Air Act
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CCSP	Climate Change Science Program
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CO_2SYS	CO2 System Calculations
Diesel HAD	2002 Diesel Health Assessment Document
DNA	deoxyribonucleic acid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DPM	diesel particulate matter
E/GDP	energy-GDP ratio
eGRID	EPA Emissions & Generation Resource Integrated Database
EIA	U.S. Energy Information Administration
EIS	environmental impact statement
EISA	Energy Independence and 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
EVs	Electric vehicles
FCVs	Fuel cell electric vehicles
FHWA	Federal Highway Administration

g CO_2e/MJ	grams of carbon dioxide equivalent per megajoule
g CO_2e/MMBtu	grams of carbon dioxide equivalent per million British thermal units
GCAM	Global Climate Change Assessment Model
GCM	general circulation model
GCRP	Global Change Research Program
GCRP	U.S. Global Change Research Program
GDP	gross domestic product
GGE	gasoline gallon equivalents
GHG	greenhouse gas
GIS	geographic information system
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
Gt	Gigatonnes
GWP	global warming potential
HD	heavy-duty
HEVs	Hybrid electric vehicles
IARC	International Agency for Research on Cancer
ICE	internal combustion engine
IEO	International Energy Outlook
IPCC	Intergovernmental Panel on Climate Change
IPCC WG1 AR5	IPCC Working Group I Fifth Assessment Report Summary for Policymakers
IRIS	Integrated Risk Information System
ISO	International Organization for Standardization
IWG	Interagency Working Group on the Social Cost of Greenhouse Gases
km^2	kilometers squared
LABs	Lead-acid batteries
LCA	life-cycle assessment
Li-ion	lithium-ion
MAGICC	Model for the Assessment of Greenhouse-Gas Induced Climate Change
MECA	Manufacturers of Emission Controls Association
MEFs	marginal emission factors
MEMA	Motor & Equipment Manufacturers Association
mg/m3	milligrams per cubic meter of air
mm	millimeters
MMbtu	million British thermal units
$MMTCO_2$	million metric tons of carbon dioxide
$MMTCO_2$e	million metric tons CO_2e
MOVES	Motor Vehicle Emissions Simulator
mpg	miles per gallon
MPGe	miles-per-gallon equivalent
MPGGE	miles per gallon of gasoline-equivalent
mph	miles per hour
MSAT	mobile-source air toxics
MY	model year
MYs 2014–2018	HD Fuel Efficiency Improvement Program Phase 1
MYs 2018–2027	HD Fuel Efficiency Improvement Program Phase 2
N_2O	nitrous oxide

NAAQS	National Ambient Air Quality Standards
NCA	National Climate Assessment
NCAT	National Coalition for Advanced Transportation
NEI	National Emissions Inventory
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NERC	National Electricity Reliability Commission
NETL	National Energy Technology Laboratory
NHTSA	National Highway Traffic Safety Administration
NO_2	nitrogen dioxide
NO_X	nitrogen oxides
NPRM	Notice of Proposed Rulemaking
NRC	National Research Council
NREL	National Renewable Energy Laboratory
objECTS	Object-Oriented Energy, Climate, and Technology Systems
OMB	Office of Management and Budget
PEV	Plug-in electric vehicles
pH	potential of hydrogen
PHEVs	Plug-in hybrid electric vehicles
PM	particulate matter
PM10	particulate matter 10 microns or less in diameter
PM2.5	particulate matter 2.5 microns or less in diameter
ppm	parts per million
PRIA	Preliminary Regulatory Impact Analysis
quads	quadrillion Btu
RCP	Representative Concentration Pathways
RF	radiative forcing
RFS2	Renewable Fuel Standard 2
RGGI	Regional Greenhouse Gas Initiative
RIA	Regulatory Impact Analysis
SAPs	synthesis and assessment products
SC-CH_4	social cost of methane
SC-CO_2	social cost of carbon
SC-N_2O	social cost of nitrous oxide
SF_6	Sulfur hexafluoride
SIP	State Implementation Plan
SO_2	sulfur dioxide
SO_X	sulfur oxides
SPR	Strategic Petroleum Reserve
TS&D	transportation, storage, and distribution
TTI	travel time index
U. S. C.	U. S. Code
UNFCCC	United Nations Framework Convention on Climate Change
UV	ultraviolet
VMT	vehicle miles traveled
VOCs	volatile organic compounds

VRFBs	Vanadium redox flow batteries
WG1	Working Group 1

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	Measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.
aerodynamic design	Features of vehicle design that can increase fuel efficiency by reducing drag.
albedo	Capacity of surfaces on Earth to reflect solar radiation back to space. High albedo has a cooling effect because the surface reflects, rather than absorbs most solar radiation.
anthropogenic	Resulting from or produced by human beings.
Atlantic Meridional Overturning Circulation (AMOC)	Mechanism for heat transport in the North Atlantic Ocean, by which warm waters are carried north and cold waters are carried toward the equator.
attainment area	Regions where concentrations of criteria pollutants meet National Ambient Air Quality Standards (NAAQS).
attribute-based standards	Each vehicle's performance standard (fuel economy or GHG emissions) is based on the model's attribute, which NHTSA classifies as the vehicle's footprint.
biofuel	Energy sources, such as biodiesel or ethanol, made from living things or the waste that living things produce.
black carbon (elemental carbon)	Most strongly light-absorbing component of particulate matter, formed by the incomplete combustion of fossil fuels, biofuels, and biomass.
CAFE Model	Model that estimates fuel consumption and tailpipe emissions under various technology, regulatory, and market scenarios.
carbon dioxide equivalent (CO_2e)	Measure that expresses total greenhouse gas emissions in a single unit. Calculated using global warming potentials of greenhouse gases and usually measured over 100 years.
carbon sink	Reservoir in which carbon removed from the atmosphere is stored, such as a forest.
carbon storage, sequestration	The removal and storage of a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere.
compound events	Simultaneous occurrence of two or more events that collectively lead to extreme impacts.
conformity regulations, General Conformity Rule	Requirement that federal actions do not interfere with a state's ability to implement its State Implementation Plan and meet the National Ambient Air Quality Standards (NAAQS).
cooling degree days	The annual sum of the daily difference between the daily mean temperature and 65°F, when the daily mean temperature exceeds 65°F.
coordinated rulemaking	Joint rulemaking that addresses both fuel economy standards (NHTSA) and greenhouse gas emission standards (U.S. Environmental Protection Agency [EPA]).

Term	Definition
criteria pollutants	Six common pollutants for which the U.S. Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards (NAAQS): carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), fine particulate matter (PM) and airborne lead (Pb). Potential impacts of an action on ozone are evaluated based on the emissions of the ozone precursors nitrogen oxides (NO_X) and volatile organic compounds (VOCs).
cumulative impacts	Impacts caused by the action when added to other past, present, and reasonably foreseeable actions in the study area.
direct impacts	Impacts caused by the action that occur at the same time and place, or are directly related to a vehicle's fuel production and consumption.
downstream emissions	Emissions related to vehicle life-cycle stages after vehicle production, including vehicle use and disposal.
dry natural gas	Gas that is removed from natural gas liquids.
El Niño-Southern Oscillation (ENSO)	Changes in atmospheric mass or pressure between the Pacific and Indo–Australian regions that affect both sea-surface temperature increases and decreases. 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.
electric vehicle (EV)	Vehicle that runs partially, primarily, or completely on electricity. These include hybrid electric vehicles (HEVs), battery-powered electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs).
energy intensity	Ratio of energy inputs to gross domestic product. Also a common term used in life-cycle assessment to express energy consumption per functional unit (e.g., kilowatt hours per mile).
energy security	Regular availability of affordable energy.
eutrophication	Enrichment of a water body with plant nutrients as a result of phosphorus and nitrogen inputs.
evapotranspiration	Evaporation of water from soil and land and transpiration of water from vegetation.
fuel efficiency	Amount of fuel required to perform a certain amount of work. A vehicle is more fuel-efficient if it can perform more work while consuming less fuel.
fuel pathway	Supply chain characteristics of refined gasoline and other transportation fuels, whether sourced or refined in the United States or elsewhere.
global warming potential	A greenhouse gas's contribution to global warming relative to carbon dioxide (CO_2) emissions
greenhouse gas (GHG) emissions	Emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that affect global temperature, precipitation, sea level, and ocean pH.
Greenhouse Gas Regulated Emissions, and Energy Use in Transportation (GREET) model	Model developed by Argonne National Laboratories that provides estimates of the life-cycle energy use, greenhouse gas emissions, and criteria air pollutant emissions of fuel production and vehicle use.
hazardous air pollutants	Pollutants that cause or may cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental and ecological effects. The U.S. Environmental Protection Agency (EPA) is required to control 187 hazardous air pollutants, also known as toxic air pollutants or air toxics.

Term	Definition
heating degree days	Annual sum of the daily difference between daily mean temperature and 65°F, when the daily mean temperature is below 65°F.
hydraulic fracturing	Method of releasing gas from shale formations by forcing water at high pressure into a well, thereby cracking the shale.
hydrocarbon	Organic compound consisting entirely of hydrogen and carbon.
indirect impacts	Impacts caused by the action that are later in time or farther in distance. In the life-cycle assessment of vehicle fuels, this refers to impacts caused by market forces related to vehicle fuel production.
life-cycle assessment (LCA)	Evaluation of all of the inputs and outputs over the lifetime of a product.
lithium-ion (Li-ion) battery	Batteries that use lithium in cathode chemistries; a common battery technology for electric vehicles.
maintenance area	Former nonattainment area now in compliance with the National Ambient Air Quality Standards (NAAQS).
marginal emission factor (MEF)	Factors that reflect variations in electricity emission factors from power sources with time and location; compared with average emission factors (AEF), which average these emissions over annual periods and broad regions.
maximum feasible standard	Highest achievable fuel economy standard for a particular model year.
maximum lifetime of vehicles	Age after which less than 2% of the vehicles originally produced during a model year remain in service.
mitigation	Measures that avoid, minimize, rectify, reduce, or compensate for the impacts of an action.
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.
morphology	Structural or anatomical features of a species, which may be affected by climate change.
Motor Vehicle Emissions Simulator (MOVES) model	U.S. Environmental Protection Agency (EPA) model used to calculate tailpipe emissions.
National Ambient Air Quality Standards (NAAQS)	Standards for ambient concentrations of six criteria air pollutants established by the U.S. Environmental Protection Agency (EPA) pursuant to the Clean Air Act.
NEPA scoping process	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 National Ambient Air Quality Standards (NAAQS). These areas are required to implement plans to comply with the standards within specified periods.
ocean acidification	Decrease in the pH of sea water due to the uptake of anthropogenic carbon dioxide (CO_2).
ozone (O_3)	Criteria pollutant formed by reactions among nitrogen oxides (NO_X) and volatile organic compounds (VOCs).
particulate matter (PM)	Discrete particles that include dust, dirt, soot, smoke, and liquid droplets directly emitted into the air.

Term	Definition
primary fuel	Energy sources consumed in the initial production of energy; primarily dry natural gas, petroleum, renewables, coal, nuclear, and liquefied natural gas or petroleum.
radiative forcing	Change in energy fluxes caused by a specific driver that can alter the Earth's energy budget. Positive radiative forcing leads to warming while a negative radiative forcing leads to cooling.
rebound effect	Situation in which improved fuel economy would reduce the cost of driving and, hypothetically, lead to additional driving, thus increasing emissions of air pollutants.
saltwater intrusion	Displacement of fresh surface water or groundwater by saltwater in coastal and estuarine areas.
sea-ice extent	Area of the ocean where there is at least some sea ice.
shale gas, shale oil	Natural gas or oil that is trapped in fine-grained shale formations.
thermal expansion (of water)	Change in volume of water in response to a change in temperature; a cause of sea-level rise.
tipping point	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.
transmission efficiency technology	Technology to improve engine efficiency such as increasing gears, dual clutch, and continuously variable transmissions.
unavoidable adverse impact	Impact of the action that cannot be mitigated.
upstream emissions	Emissions associated with crude-petroleum (feedstock) recovery and transportation, and with the production, refining, transportation, storage, and distribution of transportation fuels.
vanadium redox flow battery (VRFB)	Emerging battery technology in which energy is stored in an electrolyte, which is replenished during charging, thereby accelerating the recharge rate relative to existing battery technologies.
vehicle mass reduction	A means of increasing fuel efficiency by reducing vehicle weight (e.g., laser welding, hydroforming, tailor-welded blanks, aluminum casting and extrusion), and substituting lighter-weight materials for heavier materials.
vehicle miles traveled (VMT)	Total number of miles driven, typically reported annually.

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 Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks for model years (MYs) 2021 to 2026. 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 nine alternatives for setting fuel economy standards for MY 2022–2026 passenger cars and light trucks (eight action alternatives and the No Action Alternative). Additionally, some of the action alternatives would revise the currently existing CAFE standards for MY 2021. This EIS analyzes the direct, indirect, and cumulative impacts of each action alternative relative to the No Action Alternative.

Background

The Energy Policy and Conservation Act of 1975 (EPCA) mandated that NHTSA establish and implement a regulatory program for motor vehicle fuel economy, known as the CAFE program, to reduce national energy consumption. 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 less than 8,500 pounds and medium-duty passenger vehicles with a gross vehicle weight rating less than 10,000 pounds. The Secretary of Transportation has delegated responsibility for implementing the CAFE program to NHTSA.

EISA, enacted by Congress in December 2007, amended the EPCA CAFE program requirements by providing DOT additional rulemaking authority and responsibilities. Consistent with its statutory authority, in a rulemaking to establish CAFE standards for MY 2017 and beyond passenger cars and light trucks, NHTSA developed two phases of standards. The first phase included final standards for MYs 2017–2021. The second phase, covering MYs 2022–2025, included standards that were not final, due to the statutory requirement that NHTSA set average fuel economy standards not more than five model years at a time. Rather, NHTSA wrote that those standards were *augural*, meaning that they represented its best estimate, based on the information available at that time, of what levels of stringency might be maximum feasible in those model years.

On July 26, 2017, NHTSA published a Notice of Intent to prepare an EIS for new CAFE standards, which stated that NHTSA intended to publish a Notice of Proposed Rulemaking (NPRM) for MY 2022–2025 passenger cars and light trucks. To inform its development of the CAFE 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 and a Preferred Alternative. This Draft EIS is being issued concurrently with the NPRM.

Purpose and Need for the Action

In accordance with EPCA, as amended by EISA, one purpose of NHTSA's rulemaking is to establish MY 2022–2026 CAFE standards at "the maximum feasible average fuel economy level that the Secretary of Transportation decides the manufacturers can achieve in that model year." As part of this rulemaking, NHTSA is also considering whether the current MY 2021 CAFE standards are maximum feasible and, if not, to amend them as appropriate. When determining the maximum feasible levels that manufacturers can achieve in each year, EPCA requires that NHTSA consider the four statutory factors of technological feasibility, economic practicability, the effect of other motor vehicle standards of the government on fuel economy, and the need of the United States to conserve energy. In addition, the agency has the authority to—and traditionally does—consider other relevant factors, such as the effect of the CAFE standards on motor vehicle safety.

For MYs 2021–2030, NHTSA must establish separate average fuel economy standards for passenger cars and light trucks for each model year. Standards must be "based on one or more vehicle attributes related to fuel economy" and "express[ed]…in the form of a mathematical function." EISA includes another requirement, which mandates that NHTSA "prescribe annual fuel economy standard increases that increase the applicable average fuel economy standard ratably," for MYs 2011–2020. This requirement does not apply for MY 2021 and later model years.

Proposed Action and Alternatives

NHTSA's Proposed Action is setting fuel economy standards for passenger cars and light trucks in accordance with EPCA, as amended by EISA. NHTSA has selected a reasonable range of alternatives within which to set CAFE standards and to evaluate the potential environmental impacts of the proposed CAFE standards and alternatives under NEPA. In any single rulemaking under EPCA, fuel economy standards may be established for not more than five model years. For this reason, NHTSA is proposing to establish CAFE standards for MY 2022–2026 passenger cars and light trucks. In addition, some of the action alternatives would revise the current CAFE standards for MY 2021.

NHTSA has analyzed a range of action alternatives with fuel economy stringencies that increase annually, on average, 0.0 to 3.0 percent from the MY 2020 or MY 2021 standards for passenger cars and for light trucks (depending on alternative). The action alternatives also reflect different options regarding air conditioning (AC) efficiency and off-cycle technology adjustment procedures, with some alternatives phasing out those adjustments in MYs 2022–2026. This range of action alternatives, as well as the No Action Alternative, encompasses a spectrum of possible standards NHTSA could determine is maximum feasible based on the different ways the agency could weigh EPCA's four statutory factors.

The No Action Alternative (also referred to as Alternative 0 in tables and figures) assumes that NHTSA would not amend the CAFE standards for MY 2021 passenger cars and light trucks. In addition, the No Action Alternative assumes that NHTSA would finalize the MY 2022–2025 augural CAFE standards that were described in the 2012 joint final rule. Finally, for purposes of its analysis, NHTSA assumes that the MY 2025 augural CAFE standards would continue indefinitely. The No Action Alternative provides an analytical baseline against which to compare the environmental impacts of the other alternatives presented in the EIS. NHTSA also considers eight action alternatives, Alternatives 1 through 8, which would require average annual increases in fuel economy ranging from 0.0 percent for passenger cars and light trucks (Alternative 1) to 2.0 percent (passenger cars) and 3.0 percent (light trucks) (Alternative 8) from year to year. These action alternatives are as follows:

- **Alternative 1 (Preferred Alternative).** Alternative 1, which NHTSA has identified as the Preferred Alternative, would require a 0.0 percent average annual fleet-wide increase in fuel economy for both passenger cars and light trucks for MYs 2021–2026. This alternative revises the MY 2021 standards to the MY 2020 levels and carries those numbers forward for MYs 2021–2026.
- **Alternative 2**. Alternative 2 would require a 0.5 percent average annual fleet-wide increase in fuel economy for both passenger cars and light trucks for MYs 2021–2026.
- **Alternative 3.** Alternative 3 would require a 0.5 percent average annual fleet-wide increase in fuel economy for both passenger cars and light trucks for MYs 2021–2026. This alternative would phase out AC and off-cycle adjustment procedures beginning with MY 2022 and fully phase them out in MY 2026.
- **Alternative 4.** Alternative 4 would require a 1.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 2.0 percent average annual increase in fuel economy for light trucks for MYs 2021–2026.
- **Alternative 5.** Alternative 5 would require a 1.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 2.0 percent average annual increase in fuel economy for light trucks for MYs 2022–2026. Alternative 5 would make no changes to the current CAFE standards for MY 2021.
- **Alternative 6.** Alternative 6 would require a 2.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 3.0 percent average annual increase in fuel economy for light trucks for MYs 2021–2026.
- **Alternative 7.** Alternative 7 would require a 2.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 3.0 percent average annual increase in fuel economy for light trucks for MYs 2021–2026. Like Alternative 3, Alternative 7 would also phase out AC and off-cycle adjustment procedures beginning with MY 2022 and fully phase them out in MY 2026.
- **Alternative 8.** Alternative 8 would require a 2.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 3.0 percent average annual increase in fuel economy for light trucks for MYs 2022–2026. Alternative 8 would make no changes to the current CAFE standards for MY 2021.

For purposes of its analysis, NHTSA assumes that the MY 2026 CAFE standards for each alternative would continue indefinitely. Table S-1 shows the estimated average required fleet-wide fuel economy forecasts by model year for each alternative. Although Alternative 8 would establish higher fuel economy targets in MYs 2021–2026 compared to Alternative 7, Alternative 7 has the lowest fuel consumption impacts compared to the No Action Alternative in the analyses presented in this EIS. This occurs because the phase-out of AC and off-cycle adjustment procedures in Alternative 7 would be anticipated to cause manufacturers to add additional fuel-saving technology to comply with the standards. With this additional technology, achieved average fuel economy levels under Alternative 7 are projected to be higher than Alternative 8 in model years after 2026. As a result, Alternative 7 is the action alternative with the lowest environmental impacts compared to the No Action Alternative in terms of fuel consumption and emissions through 2050 and beyond.

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

Model Year	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Projected required mpg									
MY 2021	39.0	36.9	37.1	37.1	37.5	39.0	37.9	37.9	39.0
MY 2022	40.8	36.9	37.3	37.3	38.1	39.6	38.9	38.9	40.0
MY 2023	42.7	36.9	37.5	37.5	38.7	40.2	39.9	39.9	41.0
MY 2024	44.7	37.0	37.7	37.7	39.3	40.8	40.9	40.9	42.1
MY 2025	46.8	37.0	37.9	37.9	39.9	41.5	42.0	42.0	43.2
MY 2026	46.8	37.0	38.1	38.1	40.6	42.1	43.1	43.1	44.3

mpg = miles per gallon; MY = model year

The range under consideration in the alternatives encompass a spectrum of possible standards that NHTSA could select based on how the agency weighs EPCA's four statutory factors. By providing environmental analyses at discrete representative points, the decision-makers and the public can determine the projected environmental effects of points that fall between the individual alternatives. The alternatives evaluated in this EIS therefore provide decision-makers with the ability to select from a wide variety of other potential alternatives with stringencies that would increase annually at average percentage rates from 0.0 to 3.0 percent, or up to the No Action Alternative. This range includes, for example, alternatives with stringencies that would increase at different rates for passenger cars and for light trucks and stringencies that would increase at different rates in different years. These alternatives reflect differences in the degree of technology adoption across the fleet, in costs to manufacturers and consumers, and in conservation of oil and related reductions in GHGs.

Environmental Consequences

This section describes how the Proposed Action and alternatives could affect energy use, air quality, and climate, as reported in Chapter 3, *Energy*, Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, of this EIS, respectively. Air quality and climate impacts are reported for the entire light-duty vehicle fleet (passenger cars and light trucks combined); results are reported separately for passenger cars and light trucks in an appendix. Chapter 6, *Life-Cycle Assessment of Vehicle Energy, Material, and Technology Impacts,* describes the life-cycle environmental implications of some of the fuels, materials, and technologies that NHTSA forecasts vehicle manufacturers might use to comply with the Proposed Action. Chapter 7, *Other Impacts,* qualitatively describes potential additional impacts on hazardous materials and regulated wastes, historic and cultural resources, safety impacts on human health, noise, and environmental justice.

The impacts on energy use, air quality, and climate 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. The cumulative impacts associated with the Proposed Action and alternatives are discussed in Chapter 8, *Cumulative Impacts.*

To derive the direct and indirect impacts of the action alternatives, NHTSA compares each action alternative to a No Action Alternative, which reflects baseline trends that would be expected in the absence of any regulatory action as discussed above. The No Action Alternative for this EIS reflects fuel use and emission trends that would be expected if there were no change in the joint MY 2017–2025 National Program standards issued in the 2012 final rule, which include the MY 2017–2021 CAFE standards and the augural MY 2022–2025 CAFE standards.

Energy

NHTSA's proposed standards would regulate fuel economy and, therefore, affect U.S. transportation fuel consumption. Transportation fuel accounts for 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. 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. Until a decade ago, most of this increase came not from increased domestic energy production but from the increase in imports, largely for use in the transportation sector.

Petroleum is by far the largest source of energy used in the transportation sector. In 2016, petroleum supplied 91 percent of transportation energy demand, and in 2040, petroleum is expected to supply 84 percent of transportation energy demand. Transportation accounts for the largest share of total U.S. petroleum consumption. In 2016, the transportation sector accounted for 78 percent of total U.S. petroleum consumption. In 2040, transportation is expected to account for 74 percent of total U.S. petroleum consumption.[1]

With transportation expected to account for 74 percent of total petroleum consumption, U.S. net petroleum imports in 2040 are expected to result primarily from fuel consumption by light-duty and heavy-duty vehicles. The United States is poised to reverse the trend of the last four decades and achieve net energy exports starting in 2021 because of continuing increases in overall U.S. energy efficiency and recent developments in U.S. energy production.

In the future, the transportation sector will continue to be the largest consumer of U.S. petroleum and the second-largest consumer of total U.S. energy, after the industrial sector. NHTSA's analysis of fuel consumption in this EIS projects that fuel consumed by light-duty vehicles will consist predominantly of gasoline derived from petroleum for the foreseeable future.

Direct and Indirect Impacts

To calculate the impacts on fuel use for each action alternative, NHTSA subtracted projected fuel consumption under the No Action Alternative from the level under each action alternative. As the alternatives increase in stringency, total fuel consumption decreases. Table S-2 shows total 2020 to 2050 fuel consumption for each alternative and the direct and indirect fuel use impacts for each action alternative compared with the No Action Alternative through 2050. NHTSA used 2050 as the end year for its analysis as it is the year by which nearly the entire U.S. light duty vehicle fleet will be composed of MY 2021–2026 or later vehicles. This table reports total 2020 to 2050 fuel consumption in gasoline

[1] This *Summary* references pertinent data from the analysis in the EIS. Sources of such data are appropriately cited and referenced in those chapters.

gallon equivalents (GGE) for diesel, gasoline, electricity, and biofuel for cars and light trucks. Gasoline accounts for approximately 99 percent of car and light truck fuel use.

Table S-2. Fuel Consumption and Increase in Fuel Use by Alternative (billion gasoline gallon equivalent total for calendar years 2020–2050)

	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Fuel Consumption									
Cars	1,313	1,429	1,425	1,418	1,411	1,385	1,372	1,353	1,358
Light trucks	1,566	1,655	1,646	1,641	1,625	1,612	1,601	1,581	1,590
All light-duty vehicles	2,878	3,084	3,071	3,059	3,036	2,997	2,973	2,935	2,948
Increase in Fuel Use Compared to the No Action Alternative									
Cars		116	112	105	99	72	59	40	45
Light trucks		90	80	76	59	47	35	16	24
All light-duty vehicles		206	192	181	158	119	95	56	69

Total light-duty vehicle fuel consumption from 2020 to 2050 under the No Action Alternative is projected to be 2,878 billion GGE. Light-duty vehicle fuel consumption from 2020 to 2050 under the Proposed Action and alternatives is projected to range from 3,084 billion GGE under Alternative 1 to 2,935 billion gallons under Alternative 7. All of the action alternatives would increase fuel consumption compared to the No Action Alternative, with fuel consumption increases that range from 206 billion GGE under Alternative 1 to 56 billion GGE under Alternative 7.

Air Quality

Air pollution and air quality can affect public health, public welfare, and the environment. The Proposed Action and alternatives would affect air pollutant emissions and air quality, which, in turn, would affect public health and welfare and the natural environment. The air quality analysis in Chapter 4, *Air Quality*, assesses the impacts of the alternatives on emissions of pollutants of concern from mobile sources, and the resulting impacts on human health. The reductions and increases in emissions would vary by pollutant, calendar year, and action alternative.

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*: 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).

Criteria pollutants have been shown to cause the following adverse health impacts at various concentrations and exposures: 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.

In addition to criteria pollutants, motor vehicles emit some substances defined by the 1990 Clean Air Act amendments as toxic air pollutants. Toxic 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. DPM is a component of exhaust from diesel-fueled vehicles and falls almost entirely within the PM2.5 particle-size class. MSATs are also associated with adverse health impacts. 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 noncancer health impacts, 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 because of pollution controls on vehicles and regulation of the chemical content of fuels, despite continuing increases in vehicle travel and fuel consumption. 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 17.9 million tons per year of CO (30 percent of total U.S. emissions), 133,000 tons per year (2 percent) of PM2.5 emissions, and 287,000 tons per year (1 percent) of PM10 emissions. Passenger cars and light trucks contribute 93 percent of U.S. highway emissions of CO, 40 percent of highway emissions of PM2.5, and 56 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. All on-road mobile sources emit 1.8 million tons per year (11 percent of total nationwide emissions) of VOCs and 3.6 million tons per year (34 percent) of NO_X, which are chemical precursors of ozone. Passenger cars and light trucks account for 90 percent of U.S. highway emissions of VOCs and 51 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 0.68 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.

Methods

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

Key Findings for Air Quality

The EIS provides findings for air quality impacts for 2025, 2035, and 2050. In general, emissions of criteria air pollutants increase across all alternatives, with some 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 CAFE standards, upstream emissions rates, the relative proportions of gasoline and diesel in total fuel consumption reductions, and changes in vehicle miles traveled (VMT) from the rebound effect. In addition, the action alternatives would result in increased incidence of PM2.5-related adverse health impacts due to the emissions increases. Increases in adverse health outcomes include increased incidences of premature mortality, acute bronchitis, respiratory emergency room visits, and work-loss days.

Direct and Indirect Impacts

Criteria Pollutants

The air quality analysis identified the following impacts on criteria air pollutants:

- For CO, NO_X (in 2025 and 2035), and VOCs (in 2025), emissions would generally decrease across action alternatives (compared to the No Action Alternative), with the largest decreases occurring under Alternative 1 and emissions decreases getting smaller from Alternatives 1 through Alternative 8. Exceptions to this trend are for CO in 2035 and 2050, which shows the smallest emissions decrease in Alternative 7, and for NO_X in 2035, which shows a small increase under Alternative 8.
- For NO_X (in 2050), PM2.5, SO_2, and VOCs (in 2035 and 2050), emissions would generally increase across action alternatives (compared to the No Action Alternative), with the largest increases occurring under Alternative 1 and emissions increases getting smaller from Alternative 1 through Alternative 7. Exceptions to this trend are for PM2.5 and SO_2 in 2025, which show the smallest emissions increase under Alternative 8.
- Emissions increases would be largest under Alternative 1 for all criteria pollutants (except CO). By 2050, these increases would range from less than 1 percent for PM2.5 to 9 percent for SO_2. Emissions of CO would decrease across all alternatives and analysis years; the decreases would be greatest under Alternative 1 and the maximum decrease would be 5 percent.
- Under Alternative 1, emissions of all criteria pollutants in 2050 would increase except for CO, compared to emissions under the No Action Alternative. By 2050, these increases would range from 2.1 percent for NO_X to 9.1 percent for SO_2. By 2050, CO emissions would decrease by 3.4 percent.

Toxic Air Pollutants

The air quality analysis identified the following impacts on toxic air pollutants:

- Emissions of MSATs would be highest under the No Action Alternative, with the exception of DPM, which would have the lowest emissions under the No Action Alternative. Emissions of all MSATs except DPM would generally decrease across all action alternatives compared to the No Action Alternative, with the largest decreases occurring under Alternative 1 (the least stringent alternative) and the smallest decreases occurring under Alternative 7. Exceptions to this trend are for acetaldehyde, benzene, 1,3-butadiene, and formaldehyde in 2025, which show the smallest emissions decrease in Alternative 8. Emissions of DPM would be highest under Alternative 1 and then would decline across the action alternatives as fuel consumption decreases, with the smallest decreases occurring under Alternative 8 in 2025 and Alternative 7 in 2035 and 2050. The emissions changes are relatively small, less than 5 percent for all MSATs (except 10 percent for DPM) under all alternatives and years.
- Emissions changes would be greatest under Alternative 1 for all MSATs. These changes would range from a reduction of 5 percent for acetaldehyde, acrolein, and 1,3-butadiene to an increase of 10 percent for DPM.
- Under Alternative 1, emissions of all MSATs in 2050 would decline except for DPM, compared to the No Action Alternative. By 2050, emissions of formaldehyde would be reduced by about 1.5 percent, emissions of benzene by 1.9 percent, emissions of acrolein by 3.1 percent, emissions of

1,3-butadiene by 3.2 percent, and emissions of acetaldehyde by 3.6 percent. By 2050, emissions of DPM would increase by 10.5 percent.

Changes in criteria pollutant emissions in 2035 are shown by alternative in Figure S-1. Changes in toxic air pollutant emissions in 2035 are shown by alternative in Figure S-2.

Health Impacts

The air quality analysis identified the following health impacts:

- All action alternatives would result in increased adverse health impacts (mortality, acute bronchitis, respiratory emergency room visits, and work-loss days) nationwide compared to the No Action Alternative as a result of increases in emissions of PM2.5, DPM, and SO_X.
- Adverse health impacts would decrease from the least stringent alternative (Alternative 1) to the most stringent alternative (Alternative 7 in 2035 and 2050, and Alternative 8 in 2025).

Figure S-1. Nationwide Criteria Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2035 by Alternative

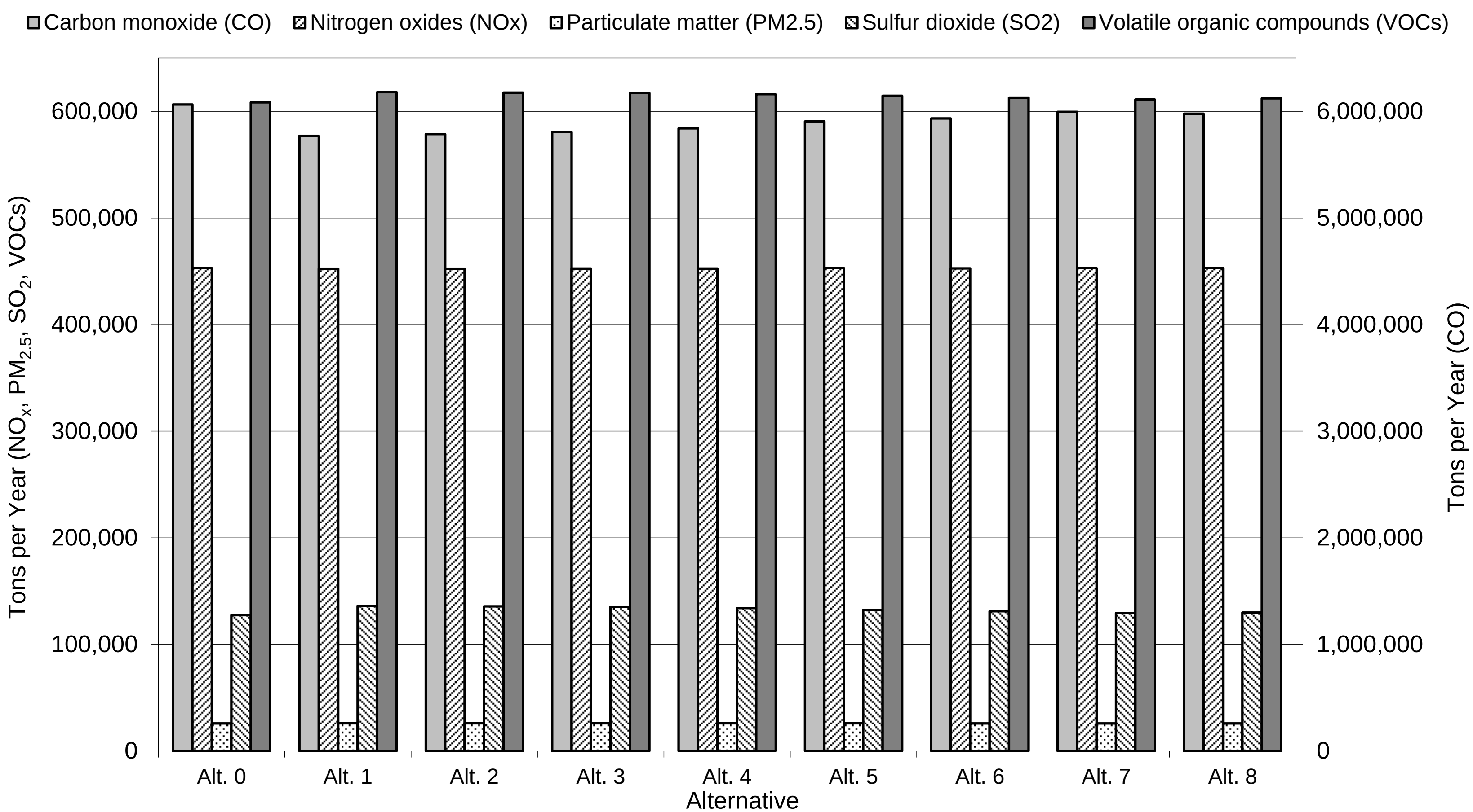
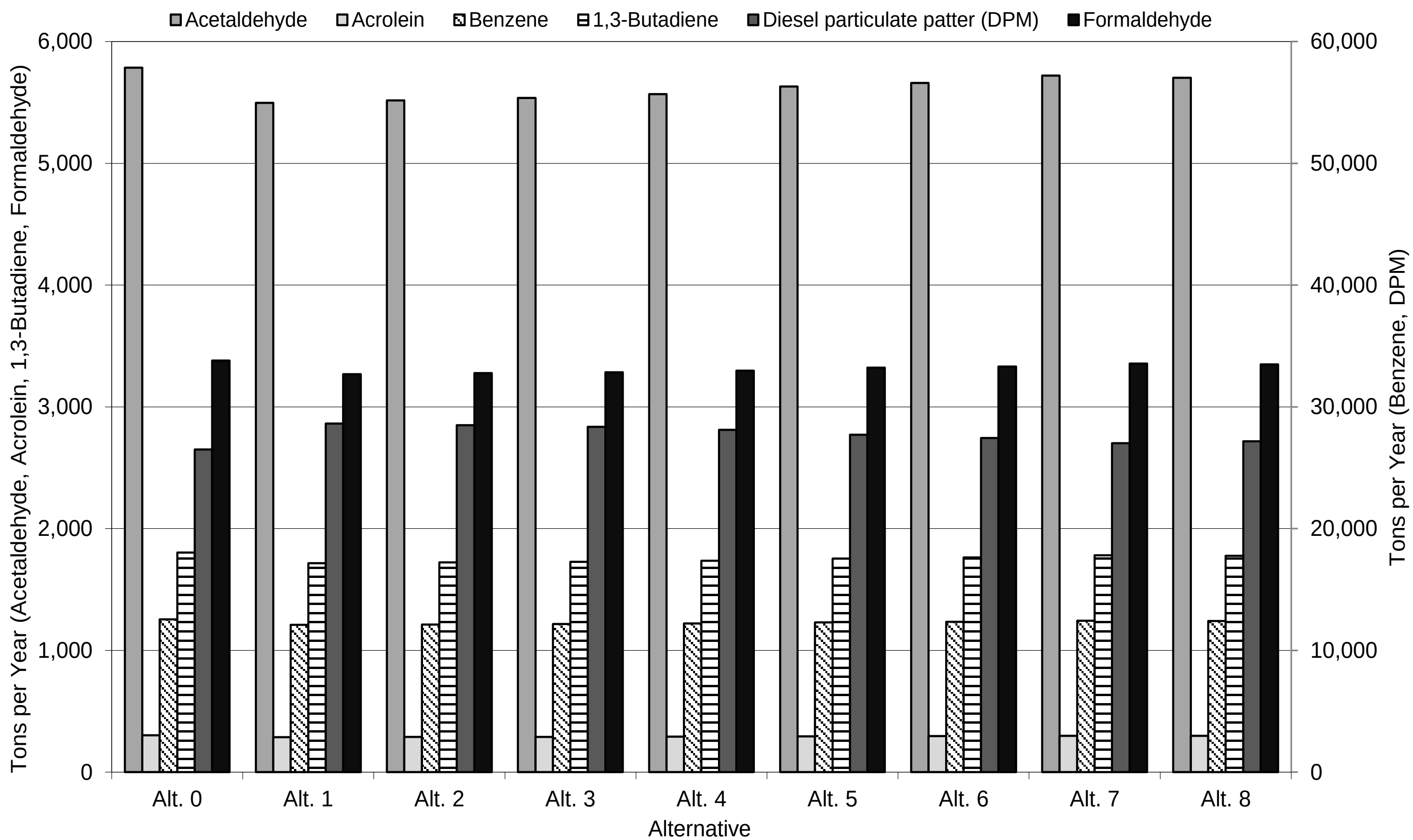


Figure S-2. Nationwide Toxic Air Pollutant Emissions (tons/year) from U.S. Passenger Cars and Light Trucks for 2035 by Alternative



Greenhouse Gas Emissions and Climate Change

This section describes how the Proposed Action and alternatives could affect the anticipated pace and extent of future changes in global climate. In this EIS, the discussion of climate change direct and indirect impacts focuses on impacts associated with increases in GHG emissions from the Proposed Action and alternatives as compared to projected GHG emissions under the No Action Alternative, including impacts on atmospheric CO_2 concentrations, global mean surface temperature, sea level, precipitation, and ocean pH.

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. Human activities, particularly fossil-fuel combustion, have been identified by the Intergovernmental Panel on Climate Change (IPCC) as primarily responsible for increasing the concentrations of GHGs in the atmosphere; this buildup of GHGs is changing Earth's energy balance. Climate simulations have been used to support arguments 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 human-made climate forcers.

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, ocean pH, and other climatic conditions. Average surface temperatures have increased since the Industrial Revolution (IPCC 2013a). From 1880 to 2016, Earth's global average surface temperature rose by more than 0.9°C (1.6°F) (GCRP 2017). Global mean sea level rose by about 1.0 to 1.7 millimeters per year from 1901 to 1990, a total of 11 to 14 centimeters (4 to 5 inches) (GCRP 2017). After 1993, global mean sea level rose at a faster rate of about 3 millimeters (0.12 inches) per year (GCRP 2017). Consequently, global mean sea level has risen by about 7 centimeters (3 inches) since 1990, and by 16 to 21 centimeters (7 to 8 inches) since 1900 (GCRP 2017).

Global atmospheric CO_2 concentration has increased 44.6 percent from approximately 278 parts per million (ppm) in 1750 (IPCC 2013b) to approximately 403 ppm in 2016 (NOAA 2017a). Atmospheric concentrations of methane (CH_4) and nitrous oxide (N_2O) increased approximately 150 and 20 percent, respectively, over roughly the same period (IPCC 2013a). IPCC concluded, "[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 *Working Group 1 (WG1) 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).

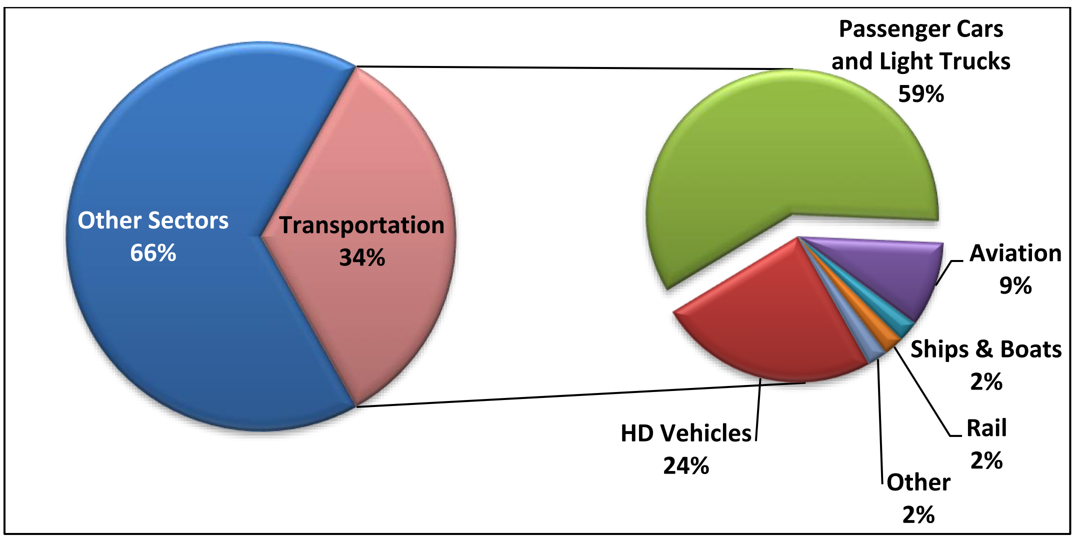
This EIS draws primarily on panel-reviewed synthesis and assessment reports from IPCC and the U.S. Global Change Research Program (GCRP), supplemented with past reports from the U.S. Climate Change Science Program (CCSP), the National Research Council, and the Arctic Council.

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

Human activities that emit GHGs to the atmosphere include fossil fuel production and combustion; industrial processes and product use; agriculture, forestry, and other land use; and waste management. Emissions of CO_2, CH_4, and N_2O account for approximately 98 percent of annual anthropogenic GHG emissions. Isotopic- and inventory-based studies have indicated that the rise in the global 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.

According to the World Resources Institute Climate Analysis Indicators Tool emissions from the United States account for approximately 15 percent of total global CO_2 emissions. EPA's National Greenhouse Gas Inventory for 1990 to 2016 indicates that, in 2016, the U.S. transportation sector contributed about 34 percent of total U.S. CO_2 emissions, with passenger cars and light trucks accounting for 59 percent of total U.S. CO_2 emissions from transportation. Therefore, approximately 20 percent of total U.S. CO_2 emissions are from passenger cars and light trucks, and these vehicles in the United States account for 3 percent of total global CO_2 emissions (based on comprehensive global CO_2 emissions data available for 2016). Figure S-3 shows the proportion of U.S. CO_2 emissions attributable to the transportation sector and the contribution of each mode of transportation to those emissions.

Figure S-3. Contribution of Transportation to U.S. Carbon Dioxide Emissions and Proportion Attributable by Mode, 2016



Source: EPA 2018
HD = heavy duty

Key Findings for Climate

The Proposed Action and alternatives would increase U.S. passenger car and light truck fuel consumption and CO_2 emissions compared with the No Action Alternative, resulting in minor increases to the anticipated increases in global CO_2 concentrations, temperature, precipitation, and sea level, and decreases in ocean pH that would otherwise occur. They could also, to a small degree, increase the impacts and risks of climate change. Uncertainty exists regarding the magnitude of impact on these climate variables, as well as to the impacts and risks of climate change.

Estimates of GHG emissions and increases are presented for each of the action alternatives. Key climate effects on atmospheric CO_2 concentration, global mean surface temperature, precipitation, sea level, and ocean pH, which result from changes in GHG emissions, are also presented for each of the action alternatives. These effects are gradual and increase over time. Changes to these climate variables are typically modeled to 2100 or longer because of the amount of time it takes to show the full extent of the effects of GHG emissions on the climate system.

The impacts of the Proposed Action and alternatives on global mean surface temperature, precipitation, sea level, and ocean pH would be extremely small in relation to global emissions trajectories. This is because of the global and multi-sectoral nature of climate change. These effects would be small, would occur on a global scale, and would not disproportionately affect the United States.

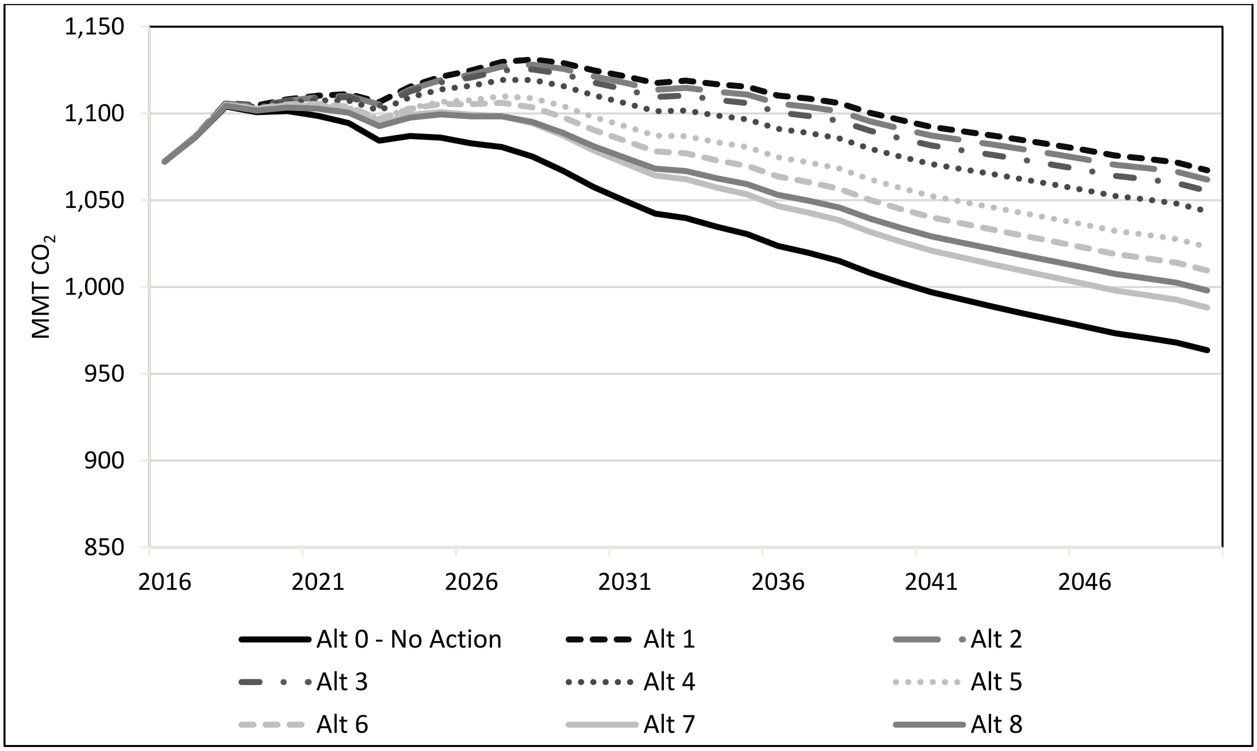
Direct and Indirect Impacts

Greenhouse Gas Emissions

The alternatives would have the following impacts related to GHG emissions:

- Figure S-4 shows projected annual CO_2 emissions from passenger cars and light trucks under each alternative. Passenger cars and light trucks are projected to emit 77,800 million metric tons of carbon dioxide ($MMTCO_2$) from 2021 through 2100 under the No Action Alternative. Alternative 1 would increase these emissions by 9 percent through 2100. Alternative 7 would increase these emissions by 2 percent through 2100. Emissions would be lowest under the No Action Alternative, while Alternatives 1 through 8 would have higher emissions than the No Action Alternative. Emissions increases would be highest under Alternative 1 and would decrease across the action alternatives (with the exception of Alternative 7, which would have lower emissions increases than Alternative 8 after 2027).
- Compared with total projected CO_2 emissions of 885 $MMTCO_2$ from all passenger cars and light trucks under the No Action Alternative in the year 2100, the Proposed Action and alternatives are expected to increase CO_2 emissions from passenger cars and light trucks in the year 2100 from 3 percent under Alternative 7 to 11 percent under Alternative 1.
- Compared with total global CO_2 emissions from all sources of 4,950,865 $MMTCO_2$ under the No Action Alternative from 2021 through 2100, the Proposed Action and alternatives are expected to increase global CO_2 emissions between 0.04 (Alternative 7) and 0.15 (Alternative 1) percent by 2100.
- The emission increases in 2025 compared with emissions under the No Action Alternative are approximately equivalent to the annual emissions from 3,456,000 vehicles under Alternative 8 to 9,178,000 vehicles under Alternative 1. (A total of 280,450,000 passenger cars and light trucks vehicles are projected to be on the road in 2025 under the No Action Alternative.)

Figure S-4. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from All U.S. Passenger Cars and Light Trucks by Alternative



$MMTCO_2$ = million metric tons of carbon dioxide

Carbon Dioxide Concentration, Global Mean Surface Temperature, Sea Level, Precipitation, and Ocean pH

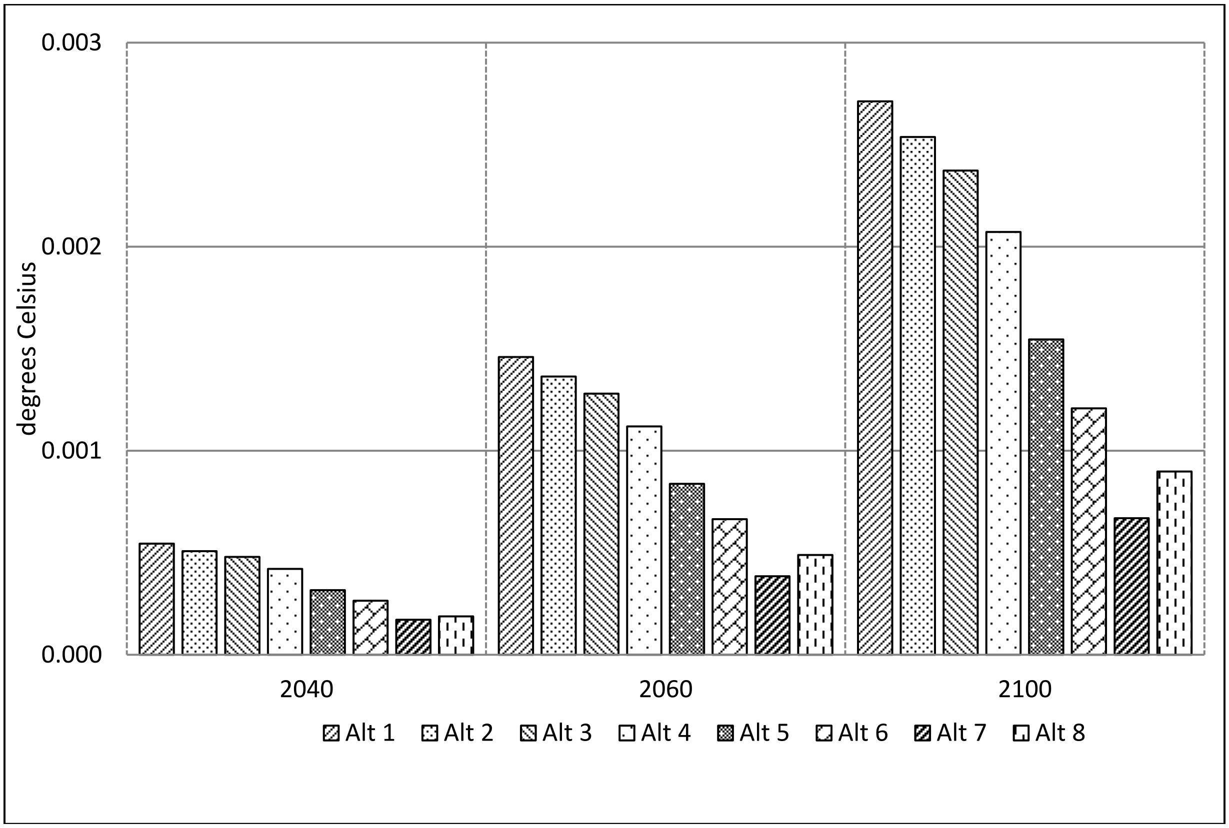
CO_2 emissions affect the concentration of CO_2 in the atmosphere, which in turn affects global temperature, sea level, precipitation, and ocean pH. For the analysis of direct and indirect impacts, NHTSA used the Global Change Assessment Model Reference scenario to represent the Reference Case emissions scenario (i.e., future global emissions assuming no additional climate policy):

- Estimated CO_2 concentrations in the atmosphere for 2100 would range from 789.76 parts per million (ppm) under Alternative 1 to approximately 789.11 ppm under the No Action Alternative, indicating a maximum atmospheric CO_2 increase of approximately 0.65 ppm compared to the No Action Alternative. Atmospheric CO_2 concentration under Alternative 7 would increase by 0.16 ppm compared with the No Action Alternative.
- Global mean surface temperature is projected to increase by approximately 3.48°C (6.27°F) under the No Action Alternative by 2100. Implementing the lowest emissions alternative (Alternative 7) would increase this projected temperature rise by 0.001°C (0.002°F), while implementing the highest emissions alternative (Alternative 1) would increase projected temperature rise by 0.003°C (0.005°F). Figure S-5 shows the increase 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 low of 76.28 centimeters (30.03 inches) under the No Action Alternative to a high of 76.34 centimeters (30.06 inches) under Alternative 1. Alternative 1 would result in an increase in sea level equal to 0.06 centimeter (0.02 inch) by 2100 compared

with the level projected under the No Action Alternative compared to an increase under Alternative 7 of 0.01 centimeter (0.004 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 increased further by less than 0.01 percent.
- Ocean pH in 2100 is anticipated to be 8.2716 under Alternative 7, about 0.0001 less than the No Action Alternative. Under Alternative 1, ocean pH in 2100 would be 8.2713, or 0.0003 less than the No Action Alternative.

Figure S-5. Increase in Global Mean Surface Temperature Compared with the No Action Alternative



Cumulative Impacts

The cumulative impact analysis evaluates the impact of the Proposed Action and alternatives in combination with other past, present, and reasonably foreseeable future actions that affect the same resource. The other actions that contribute to cumulative impacts can vary by resource and are defined independently for each resource. However, the underlying inputs, models, and assumptions of the CAFE model already take into account many past, present, and reasonably foreseeable future actions that affect U.S. transportation sector fuel use and U.S. mobile source air pollutant emissions. Therefore, the analysis of direct and indirect impacts of the Proposed Action and alternatives inherently incorporates projections about the impacts of past, present, and reasonably foreseeable future actions in order to develop a realistic baseline.

For energy and air quality, the focus of the cumulative impacts analysis is on recent Executive Orders and changes in national energy policy, as well as on trends in electric vehicle sales and use. For climate, the analysis reflects potential actions in global climate change policy to control GHG emissions. The cumulative impacts analysis for climate also includes qualitative discussions of the potential cumulative impacts of climate change on key natural and human resources and the potential nonclimate effects of CO_2.

Energy

The recent Presidential Executive Order on Promoting Energy Independence and Economic Growth (EO 13783, issued March 28, 2017) could substantively affect energy supply. EO 13783 requires that executive departments and agencies "review existing regulations that potentially burden the development or use of domestically produced energy resources and appropriately suspend, revise, or rescind those that unduly burden the development of domestic energy resources beyond the degree necessary to protect the public interest or otherwise comply with the law." The stated goal of this initiative is to "promote clean and safe development of our Nation's vast energy resources, while at the same time avoiding regulatory burdens that unnecessarily encumber energy production, constrain economic growth, and prevent job creation." EO 13783 also recognizes that "prudent development of these natural resources is essential to ensuring the Nation's geopolitical security."

The ongoing implementation of EO 13783 could affect cumulative energy impacts in many different ways. Eliminating unnecessary regulatory burdens that restrain oil exploration could increase U.S. oil production and thereby reduce the price of gasoline and diesel fuel. Lower-priced fuel may result in consumers purchasing a higher proportion of light trucks compared to passenger cars, resulting in lower overall new vehicle fuel economy. Alternatively, cheaper fuel prices may result in increased vehicle miles traveled (i.e., the rebound effect), resulting in increased U.S. vehicle use of these fuels. On the other hand, it is also possible that eliminating regulatory burdens that increase the cost of electricity could reduce electricity prices paid to operate electric vehicles and thereby increase demand for electric vehicles.

Although EO 13783 is expected to result in future actions that are likely to have substantive cumulative impacts on U.S. energy supply and associated impacts on U.S. light-duty vehicle fuel consumption, the variety of potential impacts on different energy sources and end-use sectors is too complex to support specific quantitative estimates of impacts on U.S. light-duty vehicle fuel consumption at this time.

In addition to U.S. energy policy, manufacturer investments in plug-in electric vehicle (PEV) technologies and manufacturing in response to strict government mandates (including foreign PEV quotas) may affect market trends and energy use over the long term if consumers actually choose to purchase such vehicles. Recent global trends show that PEV battery costs have declined, and vehicle manufacturers have announced more aggressive plans for global PEV production. Global efforts to comply with PEV requirements outside the United States, if enforced, could reduce the cost of PEVs, thereby reducing energy use if U.S. PEV demand increases. However, recent consumer demand for PEVs remains low compared to traditional internal combustion engine vehicles despite massive direct government subsidies, nonmonetary incentives, automaker price cross-subsidization, and future forecasts of PEV sales in the United States are subject to considerable uncertainty.

Air Quality

Market-driven changes in the energy sector are expected to affect U.S. emissions and could result in future increases or decreases in emissions. Trends in the prices of fossil fuels and the costs of renewable energy sources will affect the electricity generation mix and, consequently, the upstream emissions from energy production and distribution as well as electric vehicle use. Temporal patterns in charging of electric vehicles by vehicle owners would affect any increase in power plant emissions. Potential changes in federal regulation of emissions from power plants also could result in future increases or decreases in aggregate emissions from these sources.

The forecasts of upstream and downstream emissions that underlie the air quality impact analysis assume the continuation of existing emissions standards for vehicles, oil and gas development operations, and industrial processes such as fuel refining. These standards have become tighter over time as state and federal agencies have sought to reduce emissions to help bring nonattainment areas into attainment. To the extent that the trend toward tighter emissions standards could change in the future, total nationwide emissions from vehicles and industrial processes could change accordingly.

Cumulative changes in health impacts due to air pollution are expected to be consistent with trends in emissions. Higher emissions would be expected to lead to an overall increase in adverse health impacts while lower emissions would be expected to lead to a decrease in adverse health impacts, compared to conditions in the absence of cumulative impacts.

Greenhouse Gas Emissions and Climate Change

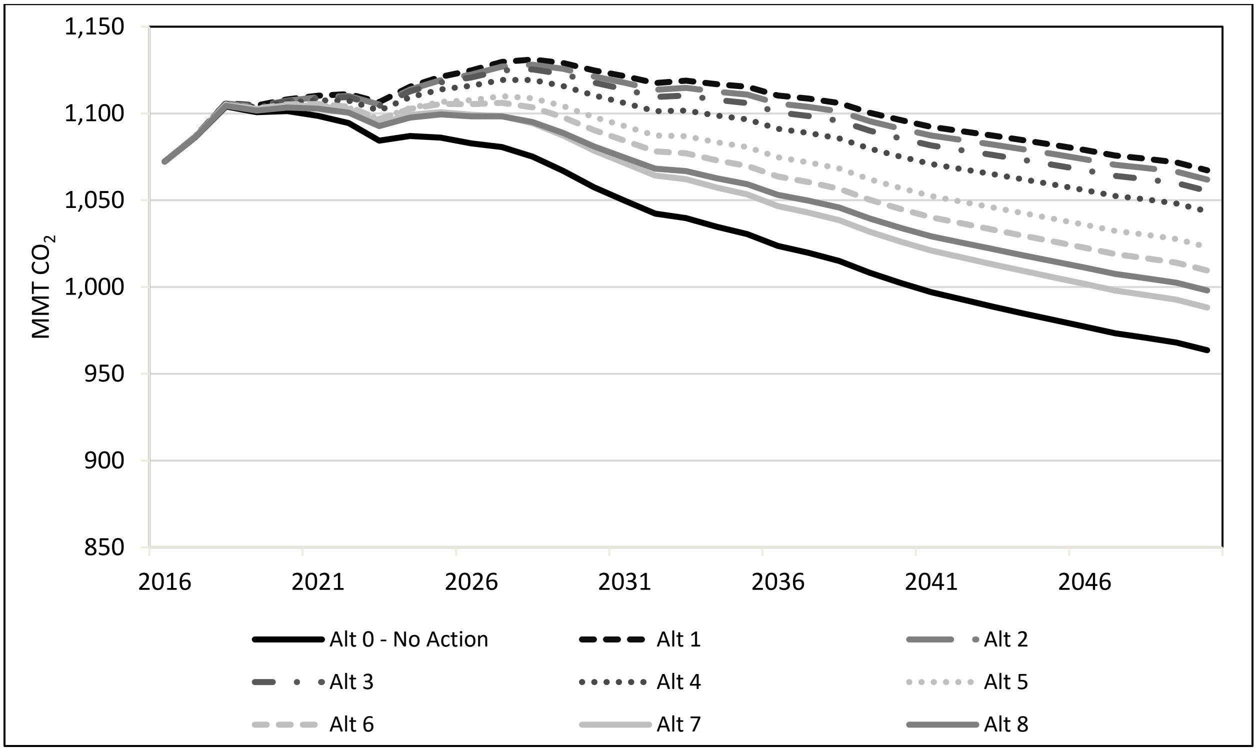
The global emissions scenario used in the cumulative impacts analysis differs from the global emissions scenario used for climate change modeling of direct and indirect impacts. In the cumulative impacts analysis, the Reference Case global emissions scenario used in the climate modeling analysis reflects reasonably foreseeable actions in global climate change policy.

Greenhouse Gas Emissions

The following cumulative impacts related to GHG emissions are anticipated:

- Projections of total emissions increases from 2021 to 2100 under the Proposed Action and alternatives and other reasonably foreseeable future actions compared with the No Action Alternative range from 1,800 $MMTCO_2$ (under Alternative 7) to 7,400 $MMTCO_2$ (under Alternative 1). The Proposed Action and alternatives would increase total vehicle emissions by between 2 percent (under Alternative 7) and 10 percent (under Alternative 1) by 2100. Figure S-6 shows projected annual CO_2 emissions from passenger cars and light trucks by alternative compared with the No Action Alternative.
- Compared with projected total global CO_2 emissions of 4,044,005 $MMTCO_2$ from all sources from 2021 to 2100, the incremental impact of this rulemaking is expected to increase global CO_2 emissions between 0.04 (Alternative 7) and 0.18 (Alternative 1) percent by 2100.

Figure S-6. Projected Annual Carbon Dioxide Emissions ($MMTCO_2$) from Passenger Cars and Light Trucks by Alternative, Cumulative Impacts



$MMTCO_2$ = million metric tons of carbon dioxide

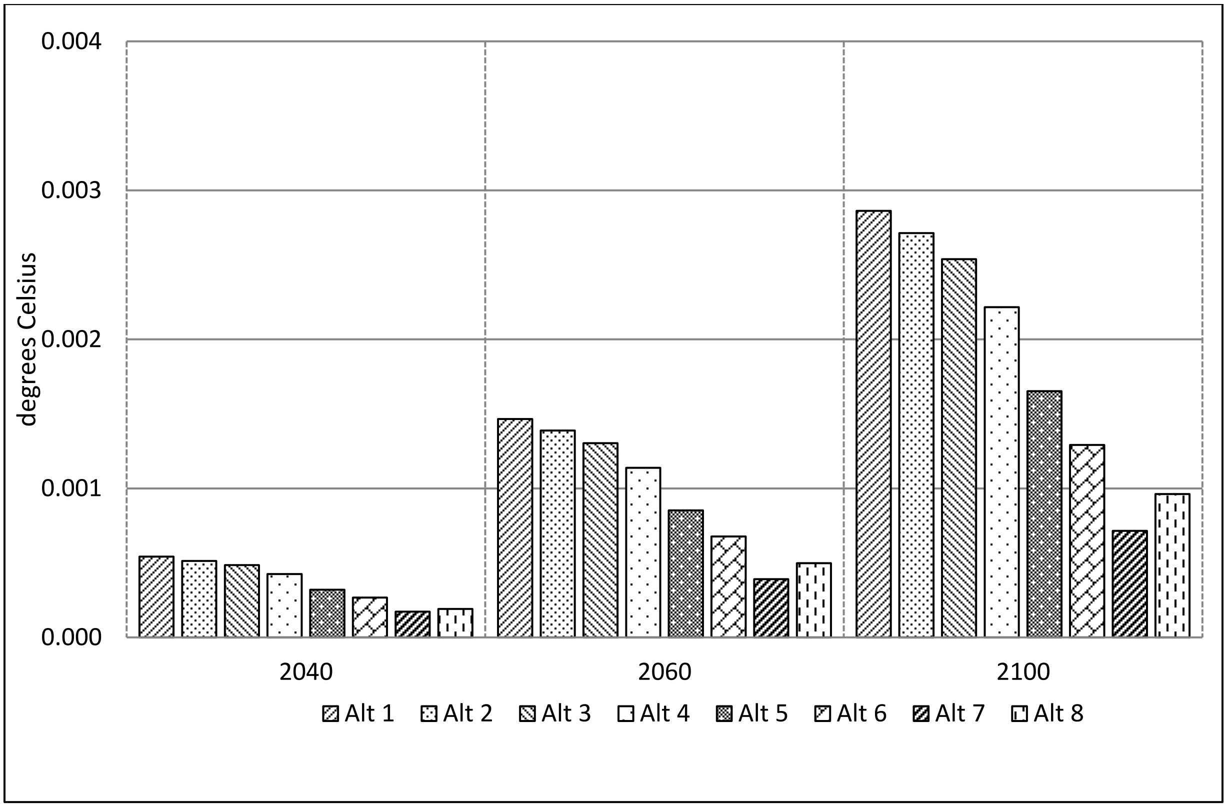
Climate Change Indicators

The following cumulative impacts related to the climate change indicators of atmospheric CO_2 concentration, global mean surface temperature, precipitation, sea level, and ocean pH are anticipated:

- Estimated atmospheric CO_2 concentrations in 2100 range from a low of 687.3 ppm under the No Action Alternative to a high of 687.9 ppm under Alternative 1. Alternative 7, the lowest CO_2 emissions alternative, would result in CO_2 concentrations of 687.4 ppm, an increase of 0.15 ppm compared with the No Action Alternative.
- Global mean surface temperature increases for the Proposed Action and alternatives compared with the No Action Alternative in 2100 range from a low of 0.001°C (0.002°F) under Alternative 7 to a high of 0.003°C (0.006°F) under Alternative 1. Figure S-7 illustrates the increases in global mean temperature under each action alternative compared with the No Action Alternative.
- Global mean precipitation is anticipated to increase by 4.77 percent by 2100 under the No Action Alternative. Under the action alternatives, this increase in precipitation would be increased further by less than 0.01 percent.
- Projected sea-level rise in 2100 ranges from a low of 70.22 centimeters (27.65 inches) under the No Action Alternative to a high of 70.28 centimeters (27.67 inches) under Alternative 1, indicating a maximum increase of sea-level rise of 0.06 centimeter (0.02 inch) by 2100. Sea-level rise under Alternative 7 would be 70.24 centimeters (27.65 inches), a 0.02-centimeter (0.01-inch) increase compared to the No Action Alternative.

- Ocean pH in 2100 is anticipated to be 8.2722 under Alternative 7, about 0.0001 less than the No Action Alternative. Under Alternative 1, ocean pH in 2100 would be 8.2719, or 0.0004 less than the No Action Alternative.

Figure S-7. Increase in Global Mean Surface Temperature Compared with the No Action Alternative, Cumulative Impacts



Health, Societal, and Environmental Impacts of Climate Change

The Proposed Action and alternatives could marginally increase 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 least stringent action alternative (Alternative 1) by the year 2100 is roughly a 0.6 ppm higher concentration of CO_2, three thousandths of a degree increase in temperature rise, a small percentage change in the rate of precipitation increase, about 0.06 centimeter (0.02 inch) of sea-level rise, and an increase of 0.0004 in ocean pH. Because the projected increases in CO_2 and climate effects are extremely small compared with total projected future climate change, they would only marginally increase the potential risks associated with climate change.

Although NHTSA does quantify the increases in monetized damages that can be attributable to each action alternative (see CO_2 Damage Reduction Benefit metric in the Preliminary Regulatory Impact Analysis (PRIA) benefits and net impacts tables), many specific impacts of climate change on health, society, and the environment cannot be estimated quantitatively. Therefore, NHTSA provides a qualitative discussion of these impacts by presenting the findings of peer-reviewed panel reports including those from IPCC, GCRP, the CCSP, the National Research Council, and the Arctic Council, among others. Because the impacts of the emissions increases under this rule would be marginal compared to global GHG emissions, the following climate impacts could be exacerbated but only to a marginal degree in proportion with the emissions increases reported. Uncertainty remains in the potential climate impacts reported, and the emissions resulting from this rule cannot be tied to any particular climate impact. The overall trends would vary by region, including in scope, intensity, and directionality (particularly for precipitation). The following types of long-term impacts were identified in the scientific literature and could be associated with climate change but would not likely be significantly affected by any of the alternatives:

- Impacts on freshwater resources could include changes in rainfall and streamflow patterns, changes in water availability paired with increasing water demand for irrigation and other needs, and decreased water quality from increased algal blooms. Flood risk could increase in response to increasing intensity of precipitation events, drought, changes in sediment transport, and changes in snowpack and the timing of snowmelt.
- 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 regions, and low-lying areas could include the loss of coastal areas due to submersion or erosion from sea-level rise and storm surge, with increased vulnerability of the built environment and associated economies. Changes in key habitats (e.g., increased temperatures, decreased oxygen, decreased ocean pH, increased salinization) and reductions in key habitats (e.g., coral reefs) may affect the distribution, abundance, and productivity of many marine species.
- 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 grazing lands in response to fire, insect infestations, increases in weeds, drought, disease outbreaks, or extreme weather events. 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, but the impact varies by species and location. Many marine fish species could migrate to deeper or colder water in response to rising ocean temperatures, and global potential fish catches could decrease. 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 affect water and energy supplies, wastewater and stormwater systems, transportation, telecommunications, provision of social services, incomes (especially agricultural), 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 increases in mortality and morbidity due to excessive heat and other extreme weather events, increases in respiratory conditions due to poor air quality and aeroallergens, increases in water and food-borne diseases, increases in mental health issues, and changes in the seasonal patterns and range of vector-borne diseases. The most disadvantaged groups such as children, the elderly, the 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 or restricted migration, increased risk of armed

conflicts, reduction in adequate essential services such as water and energy, and increased geopolitical rivalry.

In addition to the individual impacts of climate change on various sectors, compound events may occur more frequently. These events consist of two or more extreme weather events occurring simultaneously or in sequence, the combination of one or more extreme events with underlying conditions that amplify the impact of the events, or combinations of events that collectively lead to extreme impacts. The impact of climate change on the frequency and severity of compound events remains uncertain, and the effects of this rule on any of them would be minimal.

CHAPTER 1 PURPOSE AND NEED FOR THE PROPOSED ACTION

1.1 Introduction

The Energy Policy and Conservation Act of 1975 (EPCA)[1] established the Corporate Average Fuel Economy (CAFE) program as part of a comprehensive approach to federal energy policy. In order to reduce national energy consumption, EPCA directs the National Highway Traffic Safety Administration (NHTSA) within the U.S. Department of Transportation (DOT) to prescribe and enforce average fuel economy standards for passenger cars and light trucks sold in the United States.[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. These are motor vehicles with a gross vehicle weight rating of less than 8,500 pounds, and medium-duty passenger vehicles with a gross vehicle weight rating of less than 10,000 pounds.

NHTSA has set fuel economy standards since the 1970s. In recent years, NHTSA issued final CAFE standards for model year (MY) 2011 passenger cars and light trucks,[4] MY 2012–2016 passenger cars and light trucks,[5] and MY 2017 and beyond passenger cars and light trucks.[6] NHTSA also established, pursuant to EISA, the first fuel efficiency standards for medium- and heavy-duty vehicles for MYs 2014–2018 (HD Fuel Efficiency Improvement Program Phase 1)[7] and MYs 2018–2027 (Phase 2).[8] Because of the direct relationship between fuel economy and greenhouse gas (GHG) emissions in motor vehicles, beginning with the MY 2012–2016 CAFE rulemaking, NHTSA has issued its light-duty fuel economy and medium- and heavy-duty fuel efficiency standards in joint rulemakings with the U.S. Environmental

[1] Public Law (Pub. L.) No. 94-163, 89 Stat. 871 (Dec. 22, 1975). EPCA was enacted for the purpose of serving the nation's energy demands and promoting conservation methods when feasibly obtainable.

[2] The Secretary of Transportation has delegated the responsibility for implementing the CAFE program to the National Highway Traffic Safety Administration (NHTSA). 49 Code of Federal Regulations (CFR) § 1.95(a). Accordingly, the Secretary, U.S. Department of Transportation (DOT), and NHTSA are often used interchangeably in this environmental impact statement (EIS).

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

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

[6] 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).

[7] Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Final Rule, 76 FR 57106 (Sept. 15, 2011).

[8] Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2; Final Rule, 81 FR 73478 (Oct. 25, 2016).

Protection Agency (EPA). Although the agencies' programs and standards are separate,[9] they have been closely coordinated.

Consistent with its statutory authority, in the MY 2017 and beyond rulemaking for passenger cars and light trucks, NHTSA developed two phases of standards. The first phase, covering MYs 2017–2021, included final standards that were projected at the time to require, on an average industry fleet-wide basis and based on the then-anticipated fleet mix, a range from 40.3 to 41.0 miles per gallon (mpg) in MY 2021. The second phase of the CAFE program, covering MYs 2022–2025, included standards that were not final, due to the statutory requirement that NHTSA set new average fuel economy standards not more than five model years at a time. Rather, NHTSA wrote that those standards were *augural*, meaning that they represented its best estimate, based on the information available at that time, of what levels of stringency might be maximum feasible in those model years. NHTSA projected that those standards could require, on an average industry fleet-wide basis, a range from 48.7 to 49.7 mpg in MY 2025.

As part of the final rulemaking, NHTSA and EPA committed to conducting a "comprehensive mid-term evaluation and agency decision-making process" for the MY 2022–2025 standards, which was to be completed by April 1, 2018. The mid-term evaluation process reflects the long period of the MY 2017–-2025 rule as well as NHTSA's statutory obligation to conduct a *de novo* rulemaking to establish final CAFE standards for MYs 2022–2025. This environmental impact statement (EIS) has been prepared as part of that *de novo* rulemaking process, which includes fresh inputs and a fresh consideration and balancing of all relevant factors, to establish final CAFE standards for those model years.

In order to facilitate the development of the current rulemaking, on July 18, 2016, NHTSA, EPA, and the California Air Resources Board (CARB) issued a Draft Technical Assessment Report, which examined a range of matters relevant to CAFE and GHG emissions standards for MYs 2022–2025 (NHTSA 2016a).[10] On December 6, 2016, EPA published in the *Federal Register* an announcement of its proposed determination for the mid-term evaluation, which consisted of almost 1,000 pages of analyses and technical information, and gave commenters less than 1 month to respond.[11] On January 12, 2017, less than 2 weeks after the comment period closed and well over a year earlier than anticipated, the EPA Administrator signed the Final Determination of the mid-term evaluation of light-duty GHG emissions standards for MYs 2022–2025 (EPA 2017e).[12] Subsequently, EPA Administrator Scott Pruitt and Transportation Secretary Elaine L. Chao issued a joint notice announcing EPA's conclusion that it would reconsider its Final Determination in order to allow additional consultation and coordination with

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[9] NHTSA issues CAFE standards pursuant to its statutory authority under EPCA, as amended by EISA. EPA sets national carbon dioxide (CO_2) emissions standards for passenger cars and light trucks under section 202(a) of the Clean Air Act (CAA) (42 U.S.C. § 7521(a)). In addition, EPA has authority to measure passenger car and passenger car fleet fuel economy pursuant to EPCA (49 U.S.C. § 32904(c)).

[10] Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025 (July 18, 2016). Available at: https://www.nhtsa.gov/corporate-average-fuel-economy/light-duty-cafe-midterm-evaluation (Accessed: Jan. 29, 2018).

[11] Proposed Determination on the Appropriateness of the Model Year 2022–2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation, 81 FR 87927 (Dec. 6, 2016).

[12] U.S. EPA, Final Determination on the Appropriateness of the Model Year 2022–2025 Light-duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation (January 2017). Available at: https://www.epa.gov/regulations-emissions-vehicles-and-engines/midterm-evaluation-light-duty-vehicle-greenhouse-gas#previoussteps (Accessed: Jan. 29, 2018).

NHTSA in support of a national harmonized program.[13] On April 2, 2018, EPA issued a new Final Determination announcing its intention to revise the MY 2022–2025 GHG emissions standards established in 2012, determining that those standards are based on outdated information and that more recent information suggests that the standards may be too stringent.[14] The notice also explained that EPA, in partnership with NHTSA, would initiate a notice-and-comment rulemaking to further consider appropriate standards for MY 2022–2025 light-duty vehicles.

As part of its rulemaking to establish the next phase of CAFE standards, NHTSA is considering a broad range of alternatives with varying levels of stringency for MY 2022–2026 passenger cars and light trucks. In addition, some of those alternatives (including the agency's Preferred Alternative, as discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*) would revise the already finalized CAFE standards for MY 2021. Some would phase out the ability of manufacturers to generate fuel consumption improvement values for purposes of CAFE compliance due to improvements in air conditioner efficiency or the use of technologies whose benefits are not measured by the two-cycle test mandated by EPCA (*off-cycle technologies*).[15]

To inform its development of the CAFE standards for MYs 2021–2026,[16] NHTSA prepared this EIS, pursuant to the National Environmental Policy Act (NEPA), to evaluate the potential environmental impacts of these alternatives.[17] NEPA directs that federal agencies proposing "major federal actions significantly affecting the quality of the human environment" must, "to the fullest extent possible," prepare "a detailed statement" on the environmental impacts of the proposed action (including alternatives to the proposed action).[18] Although NHTSA evaluated the impacts of the augural standards in its EIS accompanying the MY 2017–2025 rulemaking (NHTSA 2012),[19] NHTSA prepared this new EIS as part of the *de novo* rulemaking in order to provide fresh consideration of all available information. This EIS analyzes, discloses, and compares the potential environmental impacts of a reasonable range of action alternatives, including a no action alternative and a Preferred Alternative, pursuant to Council on Environmental Quality (CEQ) NEPA implementing regulations, DOT Order 5610.1C, and NHTSA regulations.[20] This EIS analyzes direct, indirect, and cumulative impacts, and discusses impacts in proportion to their significance.

[13] Notice of Intention to Reconsider the Final Determination of the Mid-Term Evaluation of Greenhouse Gas Emissions Standards for Model Year 2022–2025 Light Duty Vehicles, 82 FR 14671 (Mar. 22, 2017).

[14] Notice; Withdrawal; Mid-Term Evaluation of Greenhouse Gas Emissions Standards for Model Year 2022–2025 Light-Duty Vehicles, 83 FR 16077 (Apr. 13, 2018).

[15] The range of alternatives under consideration by NHTSA is described more extensively in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, and in the Notice of Proposed Rulemaking (NPRM).

[16] For simplicity, the entire range of vehicles that may be regulated under NHTSA's proposed CAFE standards is referred to as MYs 2021–2026.

[17] 42 U.S.C. §§ 4321–4347.

[18] 42 U.S.C. § 4332.

[19] NHTSA, Final Environmental Impact Statement, Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2017–2025, Docket No. NHTSA–2011–0056 (July 2012).

[20] NEPA is codified at 42 U.S.C. §§ 4321–4347. CEQ NEPA implementing regulations are codified at 40 CFR Parts 1500–1508, and NHTSA's NEPA implementing regulations are codified at 49 CFR Part 520.

1.2 Purpose and Need

NEPA requires that agencies develop alternatives to a proposed action based on the action's purpose and need. The purpose and need statement explains why the action is needed, describes the action's intended purpose, and serves as the basis for developing the range of alternatives to be considered in the NEPA analysis.[21] In accordance with EPCA/EISA, the purpose of the rulemaking is to establish CAFE standards for MY 2022–2026 passenger cars and light trucks at "the maximum feasible average fuel economy level that the Secretary of Transportation decides the manufacturers can achieve in that model year."[22] When determining the maximum feasible levels that manufacturers can achieve in each model year, EPCA requires that NHTSA consider the four statutory factors of "technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy."[23] In addition, the agency has the authority to—and traditionally does—consider other relevant factors, such as the effect of the CAFE standards on motor vehicle safety.[24] As part of this rulemaking, NHTSA is also considering whether the already finalized MY 2021 CAFE standards are maximum feasible and, if not, NHTSA would amend them as appropriate.

NHTSA has interpreted the four EPCA statutory factors as follows:[25]

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

For MYs 2021–2030, NHTSA must establish separate average fuel economy standards for passenger cars and light trucks for each model year.[26] Standards must be "based on one or more vehicle attributes related to fuel economy" and "express[ed]…in the form of a mathematical function."[27] Two other EISA requirements, that NHTSA "prescribe annual fuel economy standard increases that increase the

[21] 40 CFR § 1502.13.

[22] 49 U.S.C. § 32902(a).

[23] 49 U.S.C. §§ 32902(a), 32902(f).

[24] *See*, *e.g.*, *Competitive Enterprise Inst. v. NHTSA*, 956 F.2d 321, 322 (D.C. Cir. 1992) (citing *Competitive Enterprise Inst. v. NHTSA*, 901 F.2d 107, 120 n.11 (D.C. Cir. 1990)) ("NHTSA has always examined the safety consequences of the CAFE standards in its overall consideration of relevant factors since its earliest rulemaking under the CAFE program.").

[25] 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).

[26] 49 U.S.C. § 32902(a), (b)(2)(B).

[27] 49 U.S.C. § 32902(b)(3)(A).

applicable average fuel economy standard ratably" and that the combined U.S. passenger car and light truck fleet achieves an average fuel economy level of not less than 35 mpg by MY 2020, apply only for MYs 2011–2020 and therefore do not apply for MY 2021 and later.[28]

1.3 Corporate Average Fuel Economy Rulemaking Process

NHTSA and EPA are announcing proposed rules to establish or amend CAFE standards and carbon dioxide (CO_2) emission standards, respectively, for light-duty vehicles for MYs 2021–2026. This EIS informs NHTSA and the public during the development of the standards as part of the rulemaking process. NHTSA and EPA have proposed coordinated standards for passenger cars, light trucks, and medium-duty passenger vehicles (referred to throughout this EIS as *passenger cars and light trucks* or *light-duty vehicles*).[29]

1.3.1 Corporate Average Fuel Economy and Greenhouse Gas Emissions Programs

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

1.3.1.1 Corporate Average Fuel Economy Program (U.S. Department of Transportation)

In 1975, Congress enacted EPCA, mandating that NHTSA establish and implement a regulatory program for motor vehicle fuel economy to meet the various facets of the need to conserve energy, including those with energy independence and security, environmental, and foreign policy implications. Fuel economy gains since 1975, due to both standards and market factors, have saved billions of barrels of oil. In December 2007, Congress enacted EISA, amending EPCA to provide additional rulemaking authority and responsibilities, as well as to set a combined average fuel economy target for MY 2020.

1.3.1.2 Greenhouse Gas Standards for Light-Duty Vehicles (U.S. Environmental Protection Agency)

Under the Clean Air Act (CAA), EPA is responsible for addressing air pollutants from motor vehicles. In 2007, the U.S. Supreme Court issued a decision on *Massachusetts v. Environmental Protection Agency*,[30] a case involving a 2003 EPA order denying a petition for rulemaking to regulate GHG emissions from

[28] 49 U.S.C. § 32902(b)(2)(C).

[29] The terms *passenger car, light truck,* and *medium-duty passenger vehicle* are defined in 49 CFR Part 523.

[30] 549 U.S. 497 (2007).

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

EPA has since found that emissions of GHGs from new motor vehicles and motor vehicle engines do cause or contribute to air pollution that can reasonably be anticipated to endanger public health and welfare.[33] The NHTSA and EPA joint final rulemakings for MY 2012–2016 and MY 2017 and beyond passenger cars and light trucks issued in 2010 and 2012, respectively, as well as EPA's current proposed rule are part of EPA's response to the U.S. Supreme Court decision.[34]

1.3.2 Proposed Action

For this EIS, NHTSA's Proposed Action is to set fuel economy standards for passenger cars and light trucks, in accordance with EPCA, as amended by EISA. In the MY 2017 and beyond rulemaking, NHTSA set final CAFE standards for MY 2017–2021 passenger cars and light trucks and augural CAFE standards for MYs 2022–2025. The MY 2022–2025 standards were augural (i.e., projected and nonbinding) because the agency's statutory authority requires it to "issue regulations . . . prescribing average fuel economy standards for at least 1, but not more than 5, model years."[35] As part of the current rulemaking, NHTSA is considering a range of alternatives for prescribing CAFE standards for MYs 2022–2026, or five model years. Some of the alternatives the agency is considering also would amend the final CAFE standards for MY 2021.[36]

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[31] Notice of Denial of Petition for Rulemaking, Control of Emissions from New Highway Vehicles and Engines, 68 FR 52922 (Sept. 8, 2003).

[32] 549 U.S. at 531-32. For more information on *Massachusetts v. Environmental Protection Agency,* see the July 30, 2008, Advance Notice of Proposed Rulemaking, Regulating Greenhouse Gas Emissions under the Clean Air Act, 73 FR 44354 at 44397.

This includes a comprehensive discussion of the litigation history, the U.S. Supreme Court findings, and subsequent actions undertaken by the Bush Administration and EPA from 2007 through 2008 in response to the Supreme Court remand.

[33] Final Rule, Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act, 74 FR 66496 (Dec. 15, 2009).

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

[35] 49 U.S.C. § 32902(b)(3)(B).

[36] NHTSA's authority to amend previously issued standards (49 U.S.C. § 32902(c)) is distinct from its authority to prescribe new average fuel economy standards for MYs 2021–2030 (49 U.S.C. § 32902(b)). As a result, the limitation on prescribing new standards for more than 5 model years (49 U.S.C. § 32902(b)(3)(B)) does not apply when the agency prescribes regulations amending previously issued standards. For more information, please see the NPRM.

1.3.2.1 Level of the Standards

NHTSA and EPA are proposing separate but coordinated standards for passenger cars and light trucks under each agency's respective statutory authority. All the alternatives under consideration by NHTSA would set CAFE standards for MYs 2022–2026, although some would also amend the MY 2021 standards. While all action alternatives would be less stringent than the No Action Alternative, all but one alternative would increase in stringency from the beginning of the regulatory period through MY 2026.[37] Under NHTSA's action alternatives, the agency currently estimates that the combined average of manufacturers' required fuel economy levels would be 36.9 to 39.0 mpg in MY 2021 and 37.0 to 44.3 mpg in MY 2026. This compares to estimated average required fuel economy levels of 39.0 mpg and 46.8 mpg in MY 2021 and MY 2026, respectively, under the No Action Alternative. Under NHTSA's proposal, also known as the Preferred Alternative, the agency currently estimates that the combined average of manufacturers' required fuel economy levels would be 36.9 mpg in MY 2021, 36.9 mpg in MY 2022, 36.9 mpg in MY 2023, 37.0 mpg in MY 2024, 37.0 mpg in MY 2025, and 37.0 mpg in MY 2026. Under EPA's proposal, issued concurrently with NHTSA's proposal, EPA estimates that manufacturers would, on average, be required to meet an estimated combined average emissions level of approximately 240 grams per mile of CO_2 in MY 2026. Because the standards are attribute-based and apply separately to each manufacturer and separately to passenger cars and light trucks, actual average required fuel economy levels will depend on the mix of vehicles manufacturers produce for sale in future model years. NHTSA has estimated the future composition of the fleet nearly 8 years into the future based on current market forecasts of future sales, and such estimates are subject to considerable uncertainty. Therefore, the average future required fuel economy under each regulatory alternative is also subject to considerable uncertainty.

The NHTSA and EPA standards are coordinated even though they are not identical. Many differences are rooted in differences in NHTSA's and EPA's respective statutory authorities. In the Notice of Proposed Rulemaking (NPRM), NHTSA and EPA invite public comments on several potential changes in the programs to improve harmonization. For example, under EPA's current program, the agency regulates hydrofluorocarbon-based refrigerant leakage in air conditioner systems, nitrous oxide, and methane emissions under its overall GHG standards. These emissions, however, have no impact on fuel economy and are not currently part of NHTSA's CAFE program. To better align the programs, EPA is proposing to exclude air conditioning refrigerants and leakage, as well as nitrous oxide and methane emissions, for compliance with CO_2 standards after MY 2020. NHTSA's and EPA's proposed standards reflect these changes.

1.3.2.2 Form of the Standards

In this rulemaking, NHTSA again proposes attribute-based standards based on vehicle footprint for passenger cars and light trucks. NHTSA adopted an attribute standard based on vehicle footprint in its Reformed CAFE program for light trucks for MYs 2008–2011[38] and extended this approach to passenger cars in the CAFE rule for MY 2011, as required by EISA.[39] NHTSA and EPA also used an attribute standard

[37] For a more complete description of the alternatives under consideration, see Chapter 2, *Proposed Action and Alternatives and Analysis Methods*.

[38] Final Rule, Average Fuel Economy Standards for Light Trucks Model Years 2008–2011, 71 FR 17566 (Apr. 6, 2006).

[39] Final Rule, Record of Decision, Average Fuel Economy Standards Passenger Cars and Light Trucks Model Year 2011, 74 FR 14196 (Mar. 30, 2009).

for the joint rules establishing standards for MY 2012–2016 and MY 2017–2025 passenger cars and light trucks.[40]

Under an attribute-based standard, each vehicle model has a performance target (fuel economy for the CAFE standards; CO_2 grams per mile for the GHG emissions standards), the level of which depends on the vehicle's attribute. As in the previous CAFE rulemaking, NHTSA proposes vehicle footprint as the attribute for CAFE standards. Vehicle footprint is one measure of vehicle size and is defined as a vehicle's wheelbase multiplied by the vehicle's track width. NHTSA believes that the footprint attribute is the most appropriate attribute on which to base the standards under consideration, as discussed in Section II.C.2 of the NPRM.

Each manufacturer would have separate standards for cars and for trucks, based on the footprint target curves promulgated by the agency and the mix of vehicles that each manufacturer produces for sale in a given model year. Generally, larger vehicles (i.e., vehicles with larger footprints) would be subject to less stringent standards (i.e., higher CO_2 gram-per-mile standards and lower CAFE standards) than smaller vehicles. This is because, typically, smaller vehicles are more capable of achieving more stringent standards than larger vehicles. The shape and stringency of the proposed curves reflect, in part, NHTSA's analysis of the technological and economic capabilities of the industry within the rulemaking timeframe.

After using vehicle footprint as the attribute to determine each specific vehicle model performance target, the manufacturers' fleet average performance is then determined by the production-weighted[41] average (for CAFE, harmonic average[42]) of those targets. The manufacturer's ultimate compliance obligation is based on that average; no individual vehicle or nameplate is required to meet or exceed its specific performance target level, but the manufacturer's fleet (either domestic passenger car, import passenger car, or light truck) on average must meet or exceed the average required level for the entire fleet in order to comply. In other words, a manufacturer's individual CAFE standards for cars and trucks would be based on the target levels associated with the footprints of its particular mix of cars and trucks manufactured in that model year. Because of the curves that represent the CAFE standard for each model year, a manufacturer with a relatively high percentage of smaller vehicles would have a higher standard than a manufacturer with a relatively low percentage of smaller vehicles.

Therefore, although a manufacturer's fleet average standard could be estimated throughout the model year based on the projected production volume of its vehicle fleet, the standard with which the manufacturer must comply would be based on its final model year vehicle production. Compliance would be determined by comparing a manufacturer's harmonically averaged fleet fuel economy level in a model year with a required fuel economy level calculated using the manufacturer's actual production levels and the targets for each vehicle it produces.[43] A manufacturer's calculation of fleet average emissions at the end of the model year would therefore be based on the production-weighted average (for CAFE, harmonic average) emissions of each model in its fleet.

[40] *See* Chapter 2 of previous CAFE EISs (NHTSA 2010, 2012).

[41] Production for sale in the United States.

[42] The harmonic average is the reciprocal of the arithmetic mean of the reciprocals of the given set of observations and is generally used when averaging units like speed or other rates and ratios.

[43] While manufacturers may use a variety of flexibility mechanisms to comply with CAFE, including credits earned for over-compliance, NHTSA is statutorily prohibited from considering manufacturers' ability to use statutorily provided flexibility mechanisms in determining what level of CAFE standards would be maximum feasible. 49 U.S.C. 32902(h).

In Section III of the NPRM, NHTSA included a full discussion of the equations and coefficients that define the passenger car and light truck curves proposed for each model year by each agency.

1.3.2.3 Program Flexibilities for Achieving Compliance

As with previous model-year rules, NHTSA has proposed standards that include several program flexibilities for achieving compliance. The following flexibility provisions are discussed in Section X of the NPRM:

- CAFE credits generated based on fleet average over-compliance.
- Air conditioning efficiency fuel consumption improvement values.
- Off-cycle fuel consumption improvement values.
- Special fuel economy calculations for dual and alternative fueled vehicles.
- Incentives for game-changing technologies performance for full-size pickup trucks, including hybridization.

Additional flexibilities are discussed in NHTSA and EPA's joint proposal. Some of these flexibilities would be available to manufacturers in aiding compliance under both NHTSA and EPA standards, but some flexibilities, such as incentives for electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles, would only be available under the EPA standard because of differences between the CAFE and CAA legal authorities. The CAA provides EPA broad discretion to create incentives for certain technologies, but NHTSA's authority under EPCA, as amended by EISA is more constrained.

As described further in Chapter 2, *Proposed Action and Alternatives and Analysis Methods,* some alternatives would phase out some of the program flexibilities made available in prior rulemakings, such as off-cycle adjustments and air conditioning efficiency improvement adjustments.

1.3.2.4 Compliance

The MY 2017 and beyond final rule, which was issued in 2012, established detailed and comprehensive regulatory provisions for compliance and enforcement under the CAFE and GHG emissions standards programs. These provisions would remain in place for model years beyond MY 2020 without additional action by the agencies. However, NHTSA and EPA have proposed minor modifications to them, as described in Section X of the NPRM.

NHTSA makes its ultimate determination of a manufacturer's CAFE compliance obligation based on official reported and verified CAFE data received from EPA.[44] The EPA-verified data is based on any considerations from NHTSA testing, its own vehicle testing, and final model year data submitted by manufacturers to EPA pursuant to 40 CFR § 600.512. EPA test procedures are contained in 40 CFR Part 600 and 40 CFR Part 86.

[44] EPA is responsible for calculating manufacturers' CAFE values so that NHTSA can determine compliance with its CAFE standards. 49 U.S.C. § 32904(e).

1.4 Cooperating Agency

Section 1501.6 of the CEQ NEPA implementing regulations emphasizes agency cooperation early in the NEPA process and authorizes a lead agency (in this case, NHTSA) to request the assistance of other agencies that have either jurisdiction by law or special expertise regarding issues considered in an EIS.[45] NHTSA invited EPA and the U.S. Department of Energy (DOE) to become cooperating agencies with NHTSA in the development of this EIS.

EPA and DOE accepted NHTSA's invitation and agreed to become cooperating agencies.[46] EPA and DOE personnel have been asked to review and comment on the draft final versions of the Draft EIS.

1.5 Public Review and Comment

On July 26, 2017, NHTSA published a notice of intent to prepare an EIS for new CAFE standards for MY 2022–2025 passenger cars and light trucks.[47] The notice described the statutory requirements for the standards, provided initial information about the NEPA process, and initiated the scoping process by requesting public input on the scope of the environmental analysis.[48] The purpose of scoping is to "deemphasize insignificant issues, narrowing the scope of the environmental impact statement process accordingly."[49] NHTSA invited the public to submit scoping comments on the notice on or before August 25, 2017, by posting to the NHTSA EIS docket (Docket No. NHTSA-2017-0069). The scoping comment period was subsequently extended to September 25, 2017.[50]

Consistent with NEPA and its implementing regulations, NHTSA mailed a copy of the notice to the following entities:

- 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.
- Governors of every state and U.S. territory.
- Organizations representing state and local governments.
- Native American tribes and tribal organizations.

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[45] 40 CFR § 1501.6.

[46] While NEPA requires NHTSA to complete an EIS for this rulemaking, EPA does not have the same statutory obligation. EPA actions under the CAA, including EPA's proposed vehicle CO_2 emission standards for light-duty vehicles under the joint rulemaking, are not subject to NEPA requirements. See Section 7(c) of the Energy Supply and Environmental Coordination Act of 1974 (15 U.S.C. § 793(c)(1)). EPA's environmental review of its proposed rule is part of the Regulatory Impact Analysis and other rulemaking documents.

[47] Notice of Intent to Prepare an Environmental Impact Statement for Model Year 2022–2025 Corporate Average Fuel Economy Standards, 82 FR 34740 (July 26, 2017).

[48] Scoping, as defined under NEPA, is an early and open process for determining the scope of issues to be addressed in an EIS and for identifying the significant issues related to a proposed action. 40 CFR § 1501.7.

[49] 40 CFR § 1500.4(g).

[50] Notice to Extend the Public Comment Period for the Notice of Intent to Prepare an Environmental Impact Statement for Model Year 2022–2025 Corporate Average Fuel Economy Standards, 82 FR 41306 (Aug. 30, 2017).

- Individuals and contacts at stakeholder organizations that NHTSA reasonably expects to be interested in the NEPA analysis for the new CAFE standards, including advocacy, industry, and other organizations.

1.5.1 Scoping Comments

Through February 2018, NHTSA received 20,107 public comments on the Notice of Intent.[51] Of these submissions, the vast majority (99 percent) were submitted by individual commenters. Of these, 18,381 were exact copies of a form letter associated with a Union of Concerned Scientists mass mail campaign. NHTSA identified 1,724 unique submissions: 1,566 variations on the Union of Concerned Scientists form letter (i.e., adding supplemental text), 158 non-Union of Concerned Scientists unique submissions, and 2 non-germane to the rule or duplicate comments. NHTSA received five submissions from state agencies: the South Dakota Department of Transportation; the Michigan Department of Transportation; the State of Hawaii; the California Air Resources Board (CARB); and a joint letter from the Attorneys General of New York, the District of Columbia, Iowa, Maine, Maryland, Massachusetts, Oregon, Pennsylvania, Vermont, and Washington (the Attorneys General). NHTSA received one submission from a local agency, the Sacramento Municipal Utility District.

NHTSA received six submissions from environmental advocacy organizations: joint comments submitted by the Acadia Center and numerous other environmental advocacy organizations (Acadia Center et al.); joint comments submitted by Sierra Club, Center for Biological Diversity, Environment America, Safe Climate Campaign, and Environmental Law & Policy Center; joint comments submitted by the Institute for Policy Integrity at New York University School of Law, Environmental Defense Fund, Natural Resources Defense Council, Sierra Club, and Union of Concerned Scientists (Institute for Policy Integrity et al.); joint comments submitted by Environmental Defense Fund, Center for Energy Efficiency and Renewable Technologies, and Clean Power Campaign (EDF et al.), Environmental Law & Policy Center, and the Chesapeake Bay Foundation.

NHTSA received 14 submissions from other organizations: Consumers Union, Consumer Federation of America, Securing America's Future Energy, American Lung Association, American Security Project, Cato Institute, BMore Indivisible, Pearson Fuels, Dana Incorporated, Reason Foundation and Strata Policy, Vermont Energy Investment Corporation, VNG.co LLC, a joint comment submitted by Alaska Public Interest Research Group (AKPIRG) and numerous other advocacy organizations (AKPIRG et al.), and a joint letter from 14 health professionals.

NHTSA received 13 submissions from vehicle industry organizations: Edison Electric Institute, NGVAmerica, Renewable Fuels Association, American Chemistry Council, Aluminum Association, Manufacturers of Emission Controls Association (MECA), Advanced Engine Systems Institute, CALSTART, Growth Energy, National Coalition for Advanced Transportation (NCAT), Alliance of Automobile Manufacturers (Alliance), Alliance of Automobile Manufacturers and Association of Global Automakers (Alliance & Global Automakers), and Motor & Equipment Manufacturers Association (MEMA). The Alliance of Automobile Manufacturers submitted a late comment to NHTSA in February 2018 that consisted of a list of studies and reports it asserted were relevant to issues that would be addressed in the EIS. NHTSA considered these studies for inclusion in the Draft EIS to the extent that the rulemaking schedule allowed. NHTSA will continue to review the comment as it prepares the Final EIS.

[51] The full comment letters are found at www.regulations.gov under the search term *NHTSA-2017-0069*, which corresponds to the docket number for this EIS. All comments will be displayed in the search results.

1.5.2 Issues Raised by Commenters

This section provides a synopsis of the subjects of the comments raised rather than addressing each specific argument presented by commenters. The issues most frequently raised by the submissions included the range of alternatives; the maximum feasible technologies; and the air quality, health, climate, and economic impacts of the proposed standards. Frequently included within these comments were references to the scientific literature and other information supporting or supplementing their comments. NHTSA has carefully reviewed the comments and has considered them during preparation of the EIS. See Appendix B, *Sources Identified in Scoping Comments*, for a list of all references provided in the scoping comments.

In addition to these comments, commenters often went beyond the traditional scoping inquiry related to the nature and content of the environmental analysis. Several commenters expressed concern over the potential reconsideration of the MY 2021 standards already issued, multiple commenters expressed opposition to the reconsideration of the MY 2022–2025 fuel economy standards provided in the MY 2017–2025 EIS, and other commenters expressed concern over other aspects of the standards as related to the NHTSA rulemaking. Comments of this nature are more directly relevant to the NHTSA rulemaking than they are to determining the scope of the environmental analysis, identifying impacts that should be analyzed in depth, or identifying impacts that require less detailed consideration. NHTSA has evaluated these comments in preparation of the NPRM and will consider them in light of all other substantive comments received before making a final decision and issuing the final rule. Although NHTSA acknowledges areas of overlap, the comments summarized in the following sections focus more specifically on the scoping process.

1.5.2.1 Range of Alternatives

The CEQ regulations require agencies to "rigorously explore and objectively evaluate all reasonable alternatives" in their EISs.[52] Where a very large or even an infinite number of possible reasonable alternatives exist, only a reasonable number of examples covering the full spectrum of alternatives must be analyzed in the EIS. In that situation, such as here, "what constitutes a reasonable range of alternatives depends on the nature of the proposal and the facts in each case."[53]

In its scoping notice, NHTSA indicated it would consider four alternatives for passenger cars and four alternatives for light trucks. Specifically, those alternatives were:

- The No Action Alternative (or baseline) against which the effects of action alternatives would be compared to demonstrate their environmental impacts. NHTSA wrote that it was considering a No Action Alternative that assumed, for purposes of NEPA analysis, that the agency would issue a rule that would continue the MY 2021 CAFE standards indefinitely because they were the last year of existing and enforceable standards it had promulgated.
- An action alternative representing the lower bound of the range of reasonable annual fuel economy standards.

[52] 40 CFR § 1502.14(a).

[53] Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations, 46 FR 18026, 18026-27 (March 23, 1981).

- A Preferred Alternative reflecting annual fuel economy standards for both passenger cars and light trucks that are maximum feasible based on a balancing of the statutory criteria.
- An action alternative representing the upper bound of the range of reasonable annual fuel economy standards.

Under this approach, the Preferred Alternative would fall at or between the lower and upper bounds. In its final rule, NHTSA would be able to select the No Action Alternative or an action alternative from any stringency level at or between the lower bound and upper bound of the range of reasonable alternatives. The following sections summarize the comments NHTSA received related to the range of alternatives it indicated were under consideration at the time the scoping notice was issued.

Structure and Range of Alternatives

Multiple commenters addressed the structure and range of alternatives that NHTSA should consider in the EIS. The Aluminum Association supported NHTSA's approach in using upper and lower bounds for the range of alternatives it considers reasonable for consideration of the future year CAFE standards as well as the determination of a Preferred Alternative inside that range. The Alliance & Global Automakers stated that bracketing a spectrum of alternatives, with a lower bound, upper bound, No Action Alternative, and Preferred Alternative, is an efficient use of resources and fully consistent with the underlying requirements for an EIS.

Multiple commenters, including MECA, CARB, and NCAT, argued that extensive evidence demonstrates that NHTSA's augural MY 2022–2025 standards, as announced in 2012, are feasible and therefore should be the lower bound of the reasonable range of alternatives in the NEPA analysis. Several of these commenters stated that, compared to projections, advanced vehicle and other fuel efficiency technologies have improved and costs have declined since the augural standards were announced in 2012. Many of these commenters suggested an upper bound of at least 7 percent, with some commenters arguing it should be even higher. CARB further stated that it would be arbitrary for NHTSA not to consider stronger standards, as there is record evidence that they are reasonable. Multiple individual commenters stated that the upper bound should be more stringent than the MY 2022–2025 nonbinding augural standards that NHTSA identified as maximum feasible in 2012. Some commenters suggested that the lower bounds be either no less stringent than the existing MY 2021 standard or the statutorily defined 35 mpg target for MY 2020.

Some commenters pushed NHTSA to analyze more aggressive action alternatives as part of the EIS. EDF et al. stated that, using EPA's inputs and modeling methods, it conducted an analysis of four scenarios that are 10, 20, 30, and 40 grams-per-mile more stringent than the current MY 2025 target (173 grams per mile), the results of which the commenter stated demonstrate clearly that the compliance pathways for these more stringent levels are cost effective and similar to those in EPA's analysis. The commenter asserted that NHTSA must reflect this reality in its assessment, fully incorporate this analysis into its evaluation, and include appropriate alternatives that are more stringent than the augural standards presented in the 2012 final rule. Further, the commenter cited studies and new data made available subsequent to the EPA's January 12, 2017 Final Determination that it asserted demonstrate that even more stringent standards than those reflected in the augural standards are feasible and highly cost-effective.

Environmental Law & Policy Center and the Attorneys General argued that, because the technological advances found by EPA and NHTSA show that the augural standards are no longer the maximum feasible standards, the EIS must consider CAFE standards that are more stringent than the augural standards. Environmental Law & Policy Center stated that NHTSA should consider a robust range of alternative standards, including those stronger than the augural standards, given that the transportation sector has now overtaken the power sector as the largest source of U.S. GHG pollution and remains dependent on oil. To identify the range of possible options, Consumer Federation of America provided a table showing three potential approaches to standard setting within the confines of the law and guidance, defining each in terms of the benefit-cost ratio it would reflect.

The State of Hawaii commented that the elimination of considerations is a critical concern and stated that the importance of valuing and assessing benefits cannot be understated, because devaluing or eliminating benefits can effectively be used to lower the maximum feasible band in NHTSA's proposed bracketing approach for CAFE standards. The commenter argued it is important that, in setting the upper bound in particular, NHTSA does not set up the analysis in such a way as to understate the potential for achieving higher standards of fuel efficiency.

Alliance & Global Automakers stated that the present reality of low gasoline prices, market demand, and actual technology performance create considerable uncertainty regarding the augural standards, but they argued that it is understandable if NHTSA decides to select the augural standards as an upper bound as part of the joint NHTSA and EPA mid-term evaluation. Cato Institute argued that the lower end of the MY 2022–2025 CAFE standards considered by NHTSA in its EIS must be the 2021 standard.

NHTSA has reviewed and considered these comments in the development of this EIS. While the agency agrees that the four-alternative bounding approach it originally considered is reasonable, the agency has opted to include a wider range of alternatives in the EIS to cover the complexity of this action. The No Action Alternative, described in Chapter 2, *Proposed Action and Alternatives and Analysis Methods,* is the most stringent alternative under consideration. Although several commenters expressed a desire for NHTSA to analyze alternatives that are more stringent than the augural standards, the agency ultimately concluded that such alternatives are beyond maximum feasible and are not reasonable for consideration here. NHTSA describes its selection of alternatives in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, and in Section IV of the NPRM.

No Action Alternative and Baselines

Several commenters, including industry organizations, environmental advocacy organizations, and state and local agencies, provided input on the No Action Alternative and baselines.

Multiple organizations, including NCAT, Acadia Center et al., EDF et al., and the Environmental Law & Policy Center, asserted that continuation of the MY 2021 standards, without reference to other currently enforceable requirements that affect fuel economy (e.g., the current MY 2022–2025 EPA light-duty GHG standards, California's Advanced Clean Cars program, and the 12 CAA Section 177 states), is not an appropriate or permissible No Action Alternative or baseline under NEPA. Several commenters, including CALSTART and Institute for Policy Integrity et al., argued that the Notice of Intent's No Action Alternative also ignores NHTSA's prior selection of parallel augural fuel economy standards for MYs 2022–2025.

The American Lung Association stated that NHTSA should retain the existing MY 2021 standards, which were carefully researched and negotiated and are being achieved ahead of schedule, as a baseline for comparison in the No Action Alternative. Similarly, Alliance & Global Automakers stated that, as has been done by NHTSA historically, it is appropriate for NHTSA to consider a previously finalized standard baseline as the No Action Alternative.

Institute for Policy Integrity et al. suggested that NHTSA's EIS should reflect the potential for change to EPA's light-duty GHG standards, given that EPA has announced its intent to reconsider the mid-term evaluation of the MY 2022–2025 light-duty GHG standards. The commenter stated the EIS can reflect this potential by analyzing the climate and other environmental and health impacts of each alternative CAFE standard level under two scenarios: (1) a scenario in which EPA's standards remain in place and (2) a scenario in which NHTSA's CAFE standards are the binding driver of fuel economy (i.e., if EPA's standards did not exist or were weaker than the NHTSA standards).

In response to these comments, NHTSA's No Action Alternative is the already finalized CAFE standards for MY 2021 and the augural CAFE standards for MYs 2022–2025. The No Action Alternative also assumes that the MY 2026 CAFE standards would be the same as the MY 2025 augural CAFE standards and that manufacturers would continue to comply with the MY 2025 augural CAFE standards indefinitely after that. Although the CAFE standards for MYs 2022–2025 are not currently enforceable, no enforceable CAFE standards currently exist for those years, and the agency believes that the augural standards are the most appropriate baseline from which to analyze impacts in this EIS. The augural standards serve as a proxy for EPA's GHG emission standards for MYs 2022–2025, which were finalized as part of the rulemaking in 2012 and coordinated with NHTSA's augural standards. They also serve as a proxy for California's light-duty vehicle GHG emissions standards, which are currently enforceable there and in other states that have adopted those standards. This approach also reflects where NHTSA last indicated it would set CAFE standards for those model years, as well as its most recent CAFE EIS analysis, where it assumed the augural standards for MYs 2022–2025 would be enforceable.

Preferred Alternative

Several commenters addressed the Preferred Alternative. Some individual commenters asserted that the idea of NHTSA selecting fuel economy standards that weaken over time is at odds with any reasonable notion of maximum feasible standards. Similarly, Consumers Union argued NHTSA should not decrease the standards from one year to the next. EDF et al. argued that NHTSA faces a high bar to provide a rational explanation for a Preferred Alternative that reverses course on established policy.

MECA stated that, given the current state of technology available to meet the augural MY 2022–2025 CAFE standards, the alternatives considered in the 2012 Final EIS are still appropriate, and the Preferred Alternative could be made more aggressive.

NHTSA has proposed a range of alternatives that, except for the Preferred Alternative, would all increase CAFE standards from one year to the next. This is a *de novo* rulemaking, but even if it were not, several courts have repeatedly confirmed that NHTSA has inherent authority to reconsider its prior determinations efficiently and in the public interest, particularly when its updated interpretation "closely fits 'the design of the statute as a whole and … its object and policy.'" *Good Samaritan Hosp. v. Shalala*, 508 U.S. 402, 417-18 (1993) (quoting *Crandon v. United States,* 494 U.S. 152, 158 (1990)). None of the alternatives under consideration would result in fuel economy standards that decrease from one year to the next.

New or More Aggressive Alternatives

Some commenters made suggestions for new alternatives for the MY 2022–2025 CAFE standards. VNG.co LLC commented that alternative proposals that provide stronger incentives for natural gas vehicles and, thus, a more feasible pathway for lower emissions from light trucks than other technologies (e.g., electric vehicles), should be measured against this baseline. Pearson Fuels asserted that NHTSA is legally obligated to consider various measures to maximize ethanol use in vehicles as a reasonable alternative because ethanol is a proven and feasible means to reduce petroleum imports, to reduce environmental impacts, and to provide significant GHG reduction benefits. An individual commenter suggested that, rather than increasingly stringent regulations, NHTSA should consider providing incentives for automakers, such as reduced tax rates or government fleet contract awards to the automaker with the most fuel-efficient fleet.

NCAT and Sacramento Municipal Utility District stated that, in defining action alternatives for analysis, NHTSA must identify and analyze technology-forcing alternatives that reflect recent advances in technology and that substantially exceed the stringency of the MY 2022–2025 augural standards. NCAT went on to state that CAFE standards can and should be technology-forcing given the timeframe of this rulemaking several years into the future, in light of EPCA's purpose of energy conservation. CALSTART stated that any EIS should consider the technology-forcing aspects of maximum standards and the economic growth realized from increased U.S. competitiveness, while also permitting states to retain the authority they currently have to require increased use of advanced technology vehicles.

NHTSA addresses the limits of its statutory authority in the NPRM. Further, the agency addresses the selection of alternatives and the technologies that are anticipated to be feasible in the timeframe of this rulemaking in Chapter 2, *Proposed Action and Alternatives and Analysis Methods,* and in Section IV (selection of alternatives) and Section II.D (technologies) of the NPRM.

1.5.2.2 Environmental Impacts

In its scoping notice, NHTSA indicated that it planned to analyze environmental impacts related to fuel and energy use, air quality, and climate change. In addition, the agency wrote that it would provide a qualitative analysis of life-cycle impacts, discuss cumulative impacts, and address other potentially affected resources, such as water resources, biological resources, land use, hazardous materials, safety, noise, historical and cultural resources, and environmental justice. This section discusses the comments related to the agency's approach to environmental analysis in this EIS.

Air Quality Impacts

Several commenters discussed air quality impacts of CAFE standards. Most of these commenters, including the Attorneys General, EDF et al., and individual commenters, emphasized the importance of increases in CAFE standards as a way to mitigate air pollutants emitted by light-duty vehicles, with some discussing the health impacts associated with specific pollutants. EDF et al. remarked that air quality would be at risk if the standards were less stringent and conducted a study of two scenarios analyzing potential emission impacts. The Chesapeake Bay Foundation commented that increasing CAFE standards would result in less nitrogen pollution, which would benefit the water quality of the Chesapeake Bay and its tributaries. An individual commenter requested that the rule include air-quality monitoring with lower quantities of the six criteria pollutants.

Some commenters, including CARB, EDF et al., and American Lung Association, urged NHTSA to analyze fully the effects of the proposed standards and alternatives on air quality. NCAT commented that NHTSA's analysis of air quality impacts must include updated projections of electricity generation fuel mix and account for the distributional impacts of adverse air pollutant effects. In analyzing the CAFE standards, this commenter and the American Lung Association recommended that NHTSA update its modeling tools to factor in recent regulatory developments and data such as the Cross-State Air Pollution Rule, Mercury and Air Toxics Standards, Tier 3 standards, standards for reducing methane and volatile organic compounds (VOCs) from new oil and gas extraction, federal carbon pollution standards for power plants, state regulatory regimes to reduce emissions from electric power generation, and changes in fuel and renewable energy capacity. Similarly, Acadia Center et al. urged NHTSA to update air quality topics to include recent data, including updated vehicle miles traveled projections, changes in the fleet mix, and deregulatory proposals, including any potential weakening of the 2015 ozone National Ambient Air Quality Standards (NAAQS).

Acadia Center et al. and an individual commenter urged NHTSA to consider the effects of climate change on increasing nitrogen oxides (NO_X), ozone, and particulate matter (PM) levels as part of the analysis of cumulative air quality impacts in the EIS. CARB and Vermont Energy Investment Corporation suggested that NHTSA take into account how the CAFE standards would affect the ability of states to meet public health regulations, including NAAQS and CAA deadlines, if the CAFE standards are weakened. Reasoning that transportation has played a substantial role in total criteria pollutant emissions, NCAT commented that vehicle emission standards are an integral part of NAAQS attainment under the CAA.

EDF et al. presented the results of an analysis in which they used EPA's Inventory Costs and Benefits Tool model to quantify the air pollutant emission reductions that would be lost for alternative MY 2022–2025 CAFE standards that are less stringent than the augural standards. Based on these results, the commenter concluded that the lost reductions in VOCs, NO_X, and PM2.5 would be consequential, especially in the years the vehicle fleet turns over.

NHTSA presents its analysis of the air quality impacts of the proposed rule and alternatives in Chapter 4, *Air Quality*. NHTSA's modeling of the fleet and air quality impacts of new CAFE standards has been updated since the preparation of its last CAFE EIS to reflect new information. Peer-reviewed studies cited by the commenters that are relevant to the agency's analysis have been incorporated into the EIS.

Health Impacts

Multiple commenters addressed air quality impacts of CAFE standards in terms of how air pollutant emissions have an impact on public health. Multiple individual commenters urged NHTSA not to weaken the CAFE standards and several recommended the standards be increased to improve air quality and public health. Other individual commenters urged NHTSA to consider that air quality has improved since CAFE standards were put in place and this improvement has resulted in better public health, yet some would like pollution to decrease further. MECA and an individual commenter remarked that the savings in health benefits from cleaner air because of transportation-related regulations that reduce car and truck emissions outweigh the costs of implementation.

CARB urged that the EIS should consider air pollution emissions; related non-monetized health impacts; criteria pollutant emissions and associated health impacts; and toxic and carcinogenic emissions and associated health, species, and other environmental impacts. Further, CARB requested that NHTSA consider whether and to what extent the environmental and health impacts associated with changes in upstream emissions from alternative CAFE standards must be considered. The American Lung

Association commented that EPA air pollution records document that Americans experience unhealthy air and transportation is a major contributing source. This commenter and EDF et al. urged NHTSA to analyze for each alternative the health effects from downstream and upstream air pollutant sources similar to and updated from the discussion contained in the 2012 EIS (e.g., updated to reflect recently adopted emission reduction requirements).

Some commenters, including CARB and NCAT, urged NHTSA to consider various health impacts from air pollutants that result from vehicle emissions, including respiratory system effects; cardiovascular illnesses; and other health risks, such as cancer from heavy metals, Alzheimer's disease, and diabetes. Several commenters, including NCAT, BMore Indivisible, and CARB, discussed the relationship between air pollution and asthma levels. A few commenters, including NCAT and American Lung Association, commented that children and adults who live and work near major roadways are at an increased risk from hazardous air pollutants that could lead to harmful health effects. NCAT urged NHTSA to analyze the health effects and geographic distribution of these impacts that would result from any reduction in stringency of the MY 2022–2025 standards.

NHTSA analyzes potential health impacts related to changes in emissions that would result from the proposed rule and alternatives in Chapter 4, *Air Quality*. That chapter has been updated since the 2012 EIS to reflect new information and the impacts of the proposed standards.

Method of Climate Analysis

A few commenters addressed specific issues regarding the EIS's method for analyzing climate change impacts of alternative CAFE standards. CARB argued against measuring climate change and GHG emissions impacts based on temperature changes solely attributable to new CAFE standards, stating such an analysis would ignore other relevant impacts such as ocean acidification. CARB instead urged NHTSA to consider the range of impacts that would result from vehicle emissions and the impact of the CAFE standards on those emissions and resulting adverse environmental impacts. CARB argued that NHTSA should apply the principles of the withdrawn Final Guidance on Considering Greenhouse Gas Emissions and Climate Change in NEPA Review. Cato Institute suggested no longer using the Intergovernmental Panel on Climate Change (IPCC) as the basis for the scope of climate change analysis in the EIS. Citing congressional testimony, the commenter argued that the IPCC model is flawed and reasoned that, in light of these errors, observation-based calculations of climate sensitivity should be used instead of forecasts.

In Chapter 4, *Air Quality*, Chapter 5, *Greenhouse Gas Emissions and Climate Change*, and Chapter 8, *Cumulative Impacts*, NHTSA has considered a wide range of the potential environmental impacts of GHG emissions. NHTSA continues to rely on the latest IPCC reports because they represent some of the best available scientific information regarding the potential impacts of climate change.

Social Cost of Carbon

Some commenters addressed NHTSA's approach to analyzing the social cost of carbon (SC-CO_2). Most of these commenters urged NHTSA to continue including an analysis of the SC-CO_2 in the EIS, following the framework and values of the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG).

Institute for Policy Integrity et al. and Chesapeake Bay Foundation expressed the need to include an analysis of the SC-CO_2 in the EIS, contrary to NHTSA's stated intention of incorporating it by reference, arguing that to do otherwise would impede agency and public review of the action. Institute for Policy

Integrity et al. reasoned that incorporating the SC-CO_2 analysis by reference would (1) create confusion because of its inconsistency with past NHTSA practices; (2) underestimate and discount the significance of climate effects without proper context; and (3) be at odds with the monetization of other costs or benefits within the EIS, undermining the goals of NEPA.

Institute for Policy Integrity et al. also asserted that uncertainty is not a reason to abandon the social cost of GHG methods; rather, they argued, uncertainty supports higher estimates of the social cost of GHGs. NCAT argued that NHTSA must take into account credible values to monetize the benefits of GHG emission reductions and not just point to the range of values being extremely wide. The Attorneys General and EDF et al. stated the need to include an analysis of the SC-CO_2 in NHTSA's EIS to address fully the benefits of changes in fuel use due to the proposed CAFE standards.

Citing NEPA and Administrative Procedure Act case law, CARB, Acadia Center et al., the Attorneys General, EDF et al., and Institute for Policy Integrity et al. urged NHTSA to monetize the benefits of reducing GHG emissions using the SC-CO_2 and stated the need to continue relying on IWG's supported values for the social costs of carbon, methane, and NO_X, which remain relevant and reliable. Some of these commenters argued that the withdrawal of certain SC-CO_2 reports under Executive Order 13783 does not call into question the validity and scientific integrity of the IWG's work, nor the independent legal requirement under NEPA to properly monetize GHG impacts. Institute for Policy Integrity et al. also stated that Office of Management and Budget (OMB) Circular A-4 instructs agencies to monetize costs and benefits whenever feasible.

Institute for Policy Integrity et al. stated its support for using IWG methods and data because of IWG's use of the three most cited and most peer-reviewed integrated assessment models, which is in line with NEPA's requirement of "scientific accuracy." The commenter cited a National Academies of Sciences report that recommended future improvements to the integrated assessment models but stated that the near-term use of social cost of GHG estimates based on the three peer-reviewed models was appropriate. Further, the commenter asserted that various estimates in peer-reviewed literature are consistent with the numbers derived from a weighted average of the three peer-reviewed models used by IWG, which would be about a 3 percent discount rate in 2016 dollars.

Citing NEPA and case law, Institute for Policy Integrity et al. also urged NHTSA to consider the worldwide and long-range character of climate damages, and stated that OMB Circular A-4's reference to effects "beyond the borders" confirms that it is appropriate for agencies to consider the global effects of U.S. GHG emissions. The commenter also argued that if all countries set their GHG emission levels based only on domestic costs and benefits, the aggregate result would be substantially suboptimal. In contrast, Alliance & Global Automakers suggested the metrics and scope for assessing both the costs and benefits of various alternatives must be national and not extraterritorial.

Institute for Policy Integrity et al. expressed support for using a 3 percent or lower discount rate in analyzing the SC-CO_2. The commenter addressed Executive Order 13783, which implicitly called into question IWG's choice not to use a 7 percent discount rate; the commenter stated that applying a 7 percent discount rate would drop the valuation essentially to zero dollars, which (1) would violate NEPA's required consideration of impacts on future generations, (2) is inconsistent with best economic practices, and (3) is inconsistent with OMB Circular A-4 requiring agency analysts to do more than rigidly apply default assumptions. The commenter also noted that in its 2015 Response to Comment document for the SC-CO_2, OMB explained that the consumption rate of interest is the correct concept to use. Additionally, the commenter asserted that uncertainty over the long time horizon of climate effects should cause analysts to choose a lower discount rate, and that use of a 7 percent rate by EPA was for a

30-year horizon, while climate effects stretch out as long as 300 years. Citing a White House Council of Economic Advisers Issue Brief, the commenter further argued because long-term interest rates have fallen, a discount rate based on the consumption rate of interest "should be at most 2 percent."

In its scoping notice, NHTSA announced that it planned not to include analysis of the monetized climate change benefits of increasing CAFE standards in the EIS, because that analysis would be included in its Regulatory Impact Analysis (RIA) (which is consistent with past practice). The RIA is subject to public notice and comment concurrently with the EIS and, therefore, the public has an opportunity to review and provide comment on those impacts concurrently with the NEPA process. NHTSA monetizes the potential costs and benefits of the Proposed Action and alternatives in the RIA; therefore, that document is the most appropriate place for discussing the SC-CO_2 and including it in the decision-making process. The discussion in the RIA is incorporated by reference in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, consistent with CEQ regulations under 40 CFR § 1502.21. NHTSA provides extensive explanation of the potential impacts of climate change in Chapter 5 as well as Chapter 8, *Cumulative Impacts*. As a result, the decision-maker and the public are provided with the full context of the potential impacts of GHG emissions and climate change.

Climate Impacts

Several commenters addressed generally the EIS's analysis of climate change impacts associated with a change in CAFE standards. Most of these commenters stated the importance of continuing to assess the impacts of climate change in the EIS, and numerous commenters provided examples of impacts that have already occurred.

The Attorneys General, Advanced Engine Systems Institute, EDF et al., and several individual commenters expressed the importance of addressing climate change impacts in the EIS because of climate change's effects on severe weather, public health and safety, economic security, increased temperatures, rising sea levels, and ocean acidification. In terms of the connection between climate change effects and vehicle fuel economy, the Attorneys General emphasized that transportation is now the largest source of GHG emissions in the United States and the only sector where CO_2 emissions increased in 2016, citing U.S. Energy Information Agency data.

CARB emphasized that NEPA requires NHTSA to consider comprehensively all environmental impacts to inform decision-makers and the public, while Acadia Center et al. stated that the analytical framework used in the 2012 EIS analysis was appropriate and should be carried forward because it is in accordance with congressional intent. NCAT asserted that the potential for uncertainty does not absolve NHTSA of its obligation to consider impacts fully, given the large volume of scientific analyses available. Acadia Center et al. and NCAT also urged the use of the latest scientific findings, and they suggested that any analysis in the upcoming EIS must build on and account for EPA's recent analysis of the MY 2022–2025 standards conducted as part of its mid-term evaluation. CARB provided a list of major scientific assessments released since 2010 that improve understanding of the climate system. CARB also stated that a level of CO_2 concentration in the atmosphere exists, which, if met, would cause abrupt and nonlinear damaging consequences to the environment, and urged NHTSA to acknowledge the impact of motor vehicle emissions and NHTSA's CAFE standards on reaching that tipping point.

The American Lung Association addressed the impacts of climate change on human health in the United States and urged NHTSA to consider the impacts on public health in the EIS. The commenter concluded that vehicle emissions play a significant role in near-term health impacts and amplify many other threats to public health.

Acadia Center et al. urged consideration of the multiplier effect that even small changes in the fuel economy standards would have on climate change. They concluded that changes in national GHG emissions would have outsized effects and should be evaluated not just as percentages, but also in real terms of tons of CO_2 or CO_2e avoided or increased. The Attorneys General commented that reducing fossil fuels emissions, particularly CO_2, that are released into the environment would decrease the severity and intensity of climate change impacts and decrease the likelihood of abrupt changes. NGVAmerica asserted that substituting low-carbon renewable natural gas for gasoline and diesel fuel can reduce GHG emissions substantially without requiring significant improvements in fuel efficiency.

The Environmental Law & Policy Center summarized recent climate change research and potential anticipated climate change impacts and concluded that each policy, including MY 2022–2025 CAFE standards, that reduces the threats of climate change is a critical contributor to global reductions in emissions and should not be measured in isolation from other policies. Acadia Center et al. also commented on the need to evaluate climate impacts in the context of a comprehensive package of emission reduction measures. Similarly, NCAT stated that analysis of the cumulative impacts of CAFE standards is particularly important as any given CAFE rule might have an individually minor effect on the environment, but the rules are collectively significant over time. Chesapeake Bay Foundation urged NHTSA to include a broad scope of analysis for climate change impacts for each action alternative, and over a period that accounts for the expected-use years of the relevant model-year vehicles. If NHTSA is considering reducing the stringency of CAFE standards, Vermont Energy Investment Corporation requested that NHTSA analyze the risk of climate change impacts in terms of the cost burden of redesigning and replacing transportation infrastructure to meet increased resiliency requirements.

NHTSA has carefully considered these comments in the development of the EIS. This EIS analyzes the potential direct, indirect, and cumulative impacts of the Proposed Action and alternatives. Cumulative impacts are "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."[54] NHTSA has considered the best available information and includes extensive analyses of the potential impacts of the Proposed Action and alternatives in the RIA and this EIS.

Cumulative Climate Impacts

Some commenters addressed cumulative climate impacts associated with NHTSA's MY 2022–2025 CAFE standards. CARB emphasized the importance of analyzing the cumulative impacts of climate change from the CAFE standards. Acadia Center et al. urged NHTSA to evaluate the cumulative impact of alternatives in the context of the multiple strategies to cut global warming pollution and stated that the EIS should consider reasonably foreseeable actions that are likely to affect GHG emissions. Similarly, American Lung Association argued that recent changes in key policy and regulatory measures that could increase emissions, such as the Clean Power Plan, should be taken into account.

Acadia Center et al. also commented on the critical role that fuel economy standards play in avoiding climate change, concluding that because the United States is the second-largest global auto market with the potential to diffuse fuel-efficient technologies across the world, NHTSA should analyze and include the benefits of technology diffusion and the associated emission benefits.

[54] 40 CFR § 1508.7.

EDF et al. suggested that NHTSA undertake a wedge analysis to characterize the magnitude of climate pollution reductions at stake, using an approach similar to that used in a 2007 EPA analysis of the U.S. transportation sector, which evaluated cumulative growth in GHG emissions. Citing case law, EDF et al. argued that CAFE and EPA GHG standards have resulted in meaningful mitigation of GHG emissions.

NHTSA analyzes the potential cumulative climate impacts of the proposed rule and alternatives in Chapter 8, *Cumulative Impacts*.

Environmental Justice

Some commenters addressed the potential environmental justice impacts of changes to fuel economy standards. Most of these commenters, including Acadia et al., CARB, and American Lung Association, urged NHTSA to address such environmental justice impacts in terms of air pollution's disproportionate health effects on minorities, low-income communities, and other traditionally disadvantaged groups. Acadia Center et al. and EDF et al. commented that the EIS should consider the geographic distribution of changes in criteria pollutants and air toxics associated with any change in the NHTSA augural standards. CARB remarked that Executive Order 12898 and Title VI of the Civil Rights Act compel NHTSA to analyze environmental justice impacts, whereas Acadia Center et al. cited EPA NEPA guidance that says federal agencies must consider environmental justice in their activities under NEPA. Acadia et al. suggested that the EIS should consider the effect, if any, of the Trump Administration's proposed decreases in federal spending on environmental justice activities.

NHTSA analyzes the potential environmental justice impacts of the proposed rule and alternatives in Chapter 7, *Other Impacts*.

Other Environmental Impacts

A few commenters suggested other environmental impacts that NHTSA should consider in the EIS. Alliance & Global Automakers recommended that NHTSA consider impacts in areas such as land use, hazardous materials, historic and cultural resources, noise, and safety, and urged NHTSA to update evaluations of those impacts to reflect the most recent scientific literature. The State of Hawaii stressed the importance of continued consideration of these well understood but difficult to quantify effects. Pearson Fuels disputed a statement in the 2012 EIS section on land use and development that land use change resulting from increased ethanol production could increase GHG emissions and cause other environmental impacts; it asserted that EPA has developed an adequate renewable fuel standard regulatory framework to ensure that indirect land use change emissions are taken into account in the evaluation of whether ethanol meets the 20 percent lifecycle GHG emissions reduction standard.

CARB commented that other impacts NHTSA must consider include those from fuel production and consumption on domestic and foreign freshwater resources, arable land, species, habitat, other natural resources, and local populations. Citing the National Historic Preservation Act, CARB also argued that if NHTSA proposes standards that may further damage historic properties via direct degradation, sea level rise, fire, flood, and other harms by increasing air pollution and climate change effects relative to the augural standards, the agency must properly consult with relevant federal and state authorities and fully disclose any impacts. CARB also addressed biological resource impacts, stating that proposed changes to CAFE standards warranted full analysis under Section 7 of the Endangered Species Act, given the direct effects, including climate change effects, that vehicle emissions have on endangered species and their habitats. CARB argued that because the U.S. Fish and Wildlife Service and many independent scientists have concluded that air pollution and climate change contribute substantially to biodiversity risk, NHTSA must consult with the Interior Secretary prior to taking any action that would weaken CAFE standards.

NHTSA summarizes other environmental impacts based on a review of relevant life-cycle assessment studies in Chapter 6, *Life-Cycle Assessment of Vehicle Energy, Material, and Technology Impacts*. In addition, NHTSA analyzes other environmental impacts of the Proposed Action and alternatives in Chapter 7, *Other Impacts*.

Mitigation and Compliance

One commenter addressed mitigation under NEPA. Acadia Center et al. commented that in the presence of potentially highly significant GHG effects and other impacts, NHTSA is obligated under the NEPA CEQ regulations to identify means to mitigate the adverse impacts associated with any proposed weakening of CAFE standards below the augural MY 2022–2025 standards.

Several commenters addressed compliance issues, mostly related to offering automakers incentives to provide compliance flexibility. Securing America's Future Energy supported incentives for advanced fuel vehicles but suggested that the focus should be on systems of vehicles, such as car sharing and ride sharing, rather than the efficiency of individual vehicles. VNG.co LLC stated that an emissions incentive for electric vehicles does not help light trucks, which are less practical for electrification than smaller cars. NGVAmerica added that the current incentives do not include natural gas vehicles. Pearson Fuels advocated for the use of ethanol for reducing energy use, supporting environmental goals, and improving energy independence. Alliance & Global Automakers recommended that modifications to vehicle classifications should be considered carefully because they can directly affect standard stringency. Consumer Federation of America developed an analysis showing that improving fuel economy lowers the total cost of driving and increases vehicle sales. Reason Foundation and Strata Policy expressed concern about the high compliance costs associated with meeting the augural MY 2022–2025 CAFE standards because resources expended on improving fuel economy are not available for investment elsewhere, such as investing in the development of autonomous vehicles, which could have environmental consequences.

NHTSA addresses mitigation in Chapter 9, *Mitigation*. The agency describes its approach to compliance flexibilities in Section X of the NPRM, and the environmental impacts of those flexibilities are included in the modeling in this EIS.

1.5.2.3 Other Rulemaking Issues

Statutory Factors

Some commenters addressed NHTSA's interpretation of its statutory authority. Several commenters addressed the four statutory factors that NHTSA must weigh under EPCA, as amended by EISA, when establishing CAFE standards: (1) technological feasibility, (2) economic practicability, (3) the effect of other motor vehicle standards of the government on fuel economy, and (4) the need of the United States to conserve energy.

Regarding the *technological feasibility* criterion, NCAT argued that CAFE standards can and should be technology-forcing. Chesapeake Bay Foundation asserted that NHTSA has the authority to set standards that challenge manufacturers, and it argued that evidence suggests that industry's meeting of the MY 2022–2025 standards will be attained without economic practicability or technological feasibility obstacles. American Chemistry Council argued NHTSA should define the technological feasibility criterion as "equipment or scientific knowledge that is reasonable to achieve within the applicable model years."

Regarding the *economic practicability* criterion, MEMA stated that NHTSA must consider the potential economic and cost implications not only to the consumers and original equipment manufacturers but also to the motor vehicle suppliers. Chesapeake Bay Foundation asserted economic practicability must be construed broadly to include consumer acceptability (i.e., any added technology costs should be netted against vehicle lifetime fuel cost savings for the consumer) and the environmental and health benefits of reduced emissions. American Chemistry Council argued NHTSA should define the economic practicability criterion as "financially viable within existing market resources."

Regarding the *effect of other motor vehicle standards* criterion, NCAT stated it includes consideration of state motor vehicle emission standards for which preemption has been waived under Section 209(b) of the CAA, such as California's and other states' Advanced Clean Cars Program regulations. Chesapeake Bay Foundation asserted that this factor should be accorded lesser weight in the analysis, because it has the potential to unduly hamper the overall purpose of EPCA to achieve greater energy conservation.

Regarding the *conserve energy* criterion, Chesapeake Bay Foundation provided several reasons for giving this factor great weight, including national security benefits of increased energy independence gained by lowering U.S. demand for imported oil, commitment of U.S. military resources to protect oil facilities and resources, implications for fuel prices, and reduction in air pollutant emissions.

NHTSA has carefully considered these comments in developing its proposal. Section V.A of the NPRM provides the agency's interpretation of these four factors and their applicability to the rulemaking considering the information available at this time.

Technological and Economic Assumptions

A few commenters, American Lung Association, NCAT, and Sacramento Municipal Utility District, addressed how NHTSA considers upstream emissions as part of its impacts analysis of the proposed CAFE standards and action alternatives. These commenters recommended that NHTSA update how the Volpe model (now referred to as the CAFE model) accounts for upstream emissions, to reflect, for example, updated projections of reductions in electric generation sector emissions that would significantly increase the benefits of advanced technology vehicles such as electric vehicles.

A few commenters addressed down-weighting as an approach that vehicle manufacturers can use to improve fuel efficiency. American Chemistry Council requested that NHTSA continue to recognize vehicle light-weighting as a strategy to achieve fuel economy improvements. Aluminum Association requested that the EIS analyze the impact that aluminum light weighting has on air pollution reduction.

A couple of commenters discussed the general economic assumptions used in NHTSA's analysis. In terms of the ability of automakers to pass on technology costs, Consumers Union urged NHTSA to recognize that markups vary, meaning profit is not necessarily proportional to cost of equipment. The commenter cited a study that it asserted shows that reductions in vehicle affordability over time are tied to luxury features, and not to fuel economy improvements. In terms of evaluating consumer acceptability, Consumers Union argued that NHTSA must consider all vehicle purchaser categories to estimate consumer welfare appropriately. Specifically, the commenter suggested that NHTSA's analysis of impacts should differentiate between (1) high-income households, which more often buy new vehicles and have relatively low price sensitivity to purchase price and fuel costs; and (2) low- and moderate-income households, which more often buy used vehicles and have a greater sensitivity to both purchase price and fuel cost. Consumers Union also stated that, if NHTSA proposes fuel economy standards that are lower than international markets, then NHTSA must model the cost of the United States lagging behind global standards for major automotive markets.

Reason Foundation and Strata Policy recommended that the EIS account for the scrappage effect, which theorizes that an increase in CAFE standards increases the demand for used vehicles by raising the price of new vehicles, which encourages longer use of less fuel-efficient older cars. The commenter argued this effect could be accounted for by using the point estimates from a 2015 study quantifying the extent to which more stringent CAFE standards encourage used cars to linger on the market, unless NHTSA can retrofit the model to newer data and a footprint-based standard. The commenter also urged NHTSA to quantify how footprint-based standards mitigate the effectiveness of fuel economy standards, citing a 2012 paper that it asserted shows a high likelihood that this upward drift in footprint sizes is encouraged by footprint-based CAFE curves.

Some commenters addressed the rebound effect. Consumers Union and Alliance & Global Automakers agreed that the impact of the rebound effect on fuel consumption and GHG emissions from the in-use fleet requires quantitative analysis. Consumers Union asserted that peer-reviewed literature generally shows that rebound effects above 10 percent represent outliers in the research. However, Reason Foundation and Strata Policy suggested that a reasonable estimate of the rebound effect would be 25.2 percent based on an Organization of Economic Cooperation and Development meta-analysis. EDF et al. presented an analysis that it asserted shows that a reduction in stringency of the MY 2021 and augural MY 2022–2025 CAFE standards would result in lost emission reductions because less stringent standards and increased gasoline production would far outweigh the impact of lower vehicle miles traveled.

Some commenters addressed how oil prices affect NHTSA's analysis of the impacts of proposed CAFE standards. Securing America's Future Energy and VNG.co LLC recommended that NHTSA's analysis include consideration of how sustained low oil prices have increased the prevalence of light trucks in the light-duty vehicle fleet, thus reducing projected benefits of the MY 2022–2025 CAFE standards. An individual commenter recommended that NHTSA update the fuel prices used in its model to reflect the latest available information. Securing America's Future Energy also urged NHTSA to expand its analysis of energy security by developing a method that more comprehensively captures the economic costs of oil dependence in the U.S. transportation sector. Because long-term oil price forecasts are inherently unreliable, Consumers Union recommended that NHTSA consider the economic and security impacts of much higher gasoline prices in its cost-benefit analysis, in line with price spikes that have occurred an average of once every decade since the oil embargo.

One commenter addressed the payback period. Consumers Union asserted that the payback period is immediate for many consumers who finance their vehicles because the additional monthly payment to cover fuel efficiency improvements is outweighed by the monthly fuel savings. The commenter urged NHTSA to look at the full vehicle lifetime of benefits and costs that are experienced by all consumers, not just new car buyers who represent a minority of the vehicle-buying public.

A few individual commenters, the Consumers Union, Consumer Federation of America, and Institute for Policy Integrity et al. discussed the discount rates NHTSA uses to quantify the costs and benefits of proposed CAFE standards and alternatives. All of these commenters suggested that the lower end of the 3 to 7 percent discount rate range is most appropriate because of factors such as low auto loan interest rates, low projected inflation rates, and the need to account for intergenerational impacts.

NHTSA has carefully considered these comments in the development of the CAFE model and its analysis. Technological and economic assumptions are addressed in Section II of the NPRM and Chapters 6 and 8 of the Preliminary Regulatory Impact Analysis (PRIA).

Maximum Feasible Technologies

Multiple commenters discussed how vehicle technologies could affect NHTSA's choice of maximum feasible standards. EDF et al., CARB, NCAT, Consumers Union, Vermont Energy Investment Corporation, and MECA commented that the pace of technology implementation into vehicles has been faster and at lower costs than originally projected in the 2012 final rule. MECA commented that technology costs have further declined since the 2016 Draft Technical Assessment Report, citing a series of light-duty fuel efficiency technology reports published by the International Council on Clean Transportation to which its members contributed. Consumers Union cited the Council's 2017 study that it says estimates that the technology costs from EPA's former analysis are overstated by 37 percent. CARB also cited several sources of additional information about advanced vehicle technologies that it recommended NHTSA consider. NCAT urged NHTSA to fully account for fuel savings benefits of increased levels of advanced transportation technologies in the EIS. Some individual commenters referenced existing hybrid and electric vehicle technologies and urged NHTSA to establish CAFE standards that would further push automakers to implement these technologies.

In contrast, an individual commenter presented an analysis of current manufacturer use of advanced vehicle technologies that the commenter asserted shows that NHTSA's model assumptions undervalue the actual cost of technology and overestimate the fuel consumption benefit. In particular, the commenter urged NHTSA to update several inputs in the market data file used in the original analysis that the commenter stated were out of date for technology already installed in the fleet. Regarding updates to the technology file, the commenter asserted that several hybrid, electric, and advanced technology diesel vehicles included in the 2017 EPA mileage guide are more expensive to own over their lifetime than their gasoline counterparts are. In addition, the commenter urged NHTSA to remove from the technology file any technologies without an operational definition to avoid any double counting of benefits.

Some commenters discussed and/or advocated for the application of specific advanced vehicle technologies that they recommended the CAFE model include as part of the updated impacts analysis of proposed CAFE standards, including electric vehicles, natural gas vehicles, ethanol-fueled vehicles, mild hybrid systems, lightweight plastic and polymer composites, autonomous vehicles, and other innovations.

NHTSA has carefully considered these comments and other information from a variety of stakeholders in developing its technology estimates for the CAFE model. More information on this topic is available in Section II.D of the NPRM and Chapter 6 of the PRIA.

Economic Impacts

Several commenters addressed various economic effects that could result from changes in CAFE standards. Multiple individual commenters stated that the augural MY 2022–2025 CAFE standards would benefit the U.S. economy through increased investment in advanced technology, which creates jobs, promotes competitiveness on the global marketplace, and saves billions of dollars through reduced fuel costs. Conversely, several individual commenters expressed concern that the U.S. economy would be negatively affected if the MY 2022–2025 standards were lowered from the augural standards announced in 2012. For example, Advanced Engine Systems Institute argued that, if NHTSA seriously entertains selecting the No Action Alternative that was described in the scoping notice (i.e., no further increase to CAFE standards following MY 2021), the agency should be prepared to incorporate the resulting costs of the job losses and dis-investment that will occur in the United States, arguing that stagnating American vehicle standards are a recipe for declining international competitiveness of the U.S. manufacturing sector, decreased U.S. investment, and lower employment.

Multiple organizations, including NCAT, MEMA, Environmental Law & Policy Center, and CARB, requested that NHTSA examine the economic benefits of strong standards. Citing multiple studies, these organizations along with others, including MECA, asserted that increasingly stringent fuel economy standards have led to the development of advanced vehicle technology industries and job growth in the United States. CARB, NCAT, MECA, and MEMA suggested that this investment in technology and jobs in the automotive industry is allowing U.S. companies to be competitive on the global market. Vermont Energy Investment Corporation and an individual commenter requested NHTSA fully analyze each alternative's effects on global competitiveness. MECA and CARB remarked that, in addition to job growth and global competitiveness, fuel-efficient vehicles save consumers money.

The Michigan Department of Transportation and the South Dakota Department of Transportation urged NHTSA to analyze increased fuel economy standards' impact on infrastructure funding. They expressed concern that, because gasoline and diesel taxes fund the nation's transportation infrastructure projects (for example, through the Federal Highway Trust Fund), if drivers spend less on fuel, the loss of revenue could cause a deficit in infrastructure funding. South Dakota Department of Transportation requested that NHTSA consider the effects of any reduced Federal Highway Trust Fund revenues on highway and bridge conditions and subsequent impacts on safety, the mobility of passengers and freight, and the national economy.

The Alliance & Global Automakers added that NHTSA should analyze the costs and benefits from improved fuel mileage standards. They reasoned that the investment needed to meet the air, safety, and fuel regulations may drive up the cost of vehicles, which would lead to a decrease in fleet turnover.

NHTSA has carefully considered these comments in the preparation of its economic analysis in the PRIA.

1.5.3 Changes Since Publication of the Scoping Notice

In developing this EIS following its scoping process, NHTSA has made three key changes from what was announced in the scoping notice. This section summarizes those changes.

First, in its scoping notice, NHTSA announced it would set CAFE standards for MY 2022–2025 passenger cars and light trucks and that it "may evaluate the MY 2021 standards it finalized in 2012 to ensure they remain 'maximum feasible."[55] In the NPRM and this EIS, NHTSA has elected to evaluate the MY 2021 standards and has proposed amending them under the Preferred Alternative. NHTSA has also proposed CAFE standards for MY 2026 based on its review of its statutory authority and the need to establish regulatory certainty for manufacturers. The public is invited to comment on the standards for MYs 2021–2026 and the analyses in the NPRM, PRIA, and Draft EIS in the appropriate dockets.

[55] Notice of Intent to Prepare an Environmental Impact Statement for Model Year 2022–2025 Corporate Average Fuel Economy Standards, 82 FR 34740, 34742 (July 26, 2017).

Second, as described previously, NHTSA indicated in the scoping notice that it would consider four alternatives for passenger cars and four alternatives for light trucks: a No Action Alternative, action alternatives representing the lower bound and upper bound of the range of reasonable annual fuel economy standards, and a Preferred Alternative reflecting its proposed determination of maximum feasible standards. Under this approach, the Preferred Alternative would fall at or between the lower and upper bounds. In its final rule, NHTSA would be able to select an alternative from any stringency level at or between the lower bound and upper bound of the range of reasonable alternatives, as well as the No Action Alternative. In this EIS, NHTSA has opted to include a wider range of alternatives to cover the range of complexity of this action. In its final rule, NHTSA may still select the No Action Alternative or an action alternative within the range of alternatives presented. Also, consistent with the 2012 CAFE EIS, NHTSA is analyzing passenger cars and light trucks together in order to streamline the document for public review.

Finally, with respect to the baseline for analysis of environmental impacts, in its scoping notice NHTSA indicated that it would consider a No Action Alternative that assumed, for purposes of NEPA analysis, that NHTSA would issue a rule that would continue the MY 2021 CAFE standards indefinitely because they were the last year of existing and enforceable standards it had promulgated. In response to public comments on the scoping notice and upon further consideration, NHTSA has determined that the No Action Alternative includes the already finalized CAFE standards for MY 2021 and the augural CAFE standards for MYs 2022–2025. Although the CAFE standards for MYs 2022–2025 are not currently enforceable, no enforceable CAFE standards currently exist for those years. This approach instead reflects where NHTSA last indicated it would set CAFE standards for those model years. It also reflects NHTSA's most recent CAFE EIS analysis, where it assumed the augural standards for MYs 2022–2025 would be enforceable. Finally, these augural standards serve as a proxy for EPA's GHG emission standards for MYs 2022–2025, which were finalized as part of the rulemaking in 2012. Additional discussion of the No Action Alternative is found in Chapter 2, *Proposed Action and Alternatives and Analysis Methods.*

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

This Draft EIS is being issued for public review and comment concurrently with the NPRM to establish passenger car and light truck CAFE emission standards. Individuals may submit their written comments on the Draft EIS, identified by docket number NHTSA-2017-0069, by any of the following methods:

- **Federal eRulemaking Portal***:* Go to http://www.regulations.gov. Follow the online instructions for submitting comments.
- **Mail:** Docket Management Facility, M–30, U.S. Department of Transportation, West Building, Ground Floor, Room W12–140, 1200 New Jersey Avenue SE., Washington, DC 20590.
- **Hand Delivery or Courier:** U.S. Department of Transportation, West Building, Ground Floor, Room W12–140, 1200 New Jersey Avenue SE., Washington, DC, between 9 a.m. and 5 p.m. Eastern time, Monday through Friday, except federal holidays.
- **Fax:** 202–493–2251.

Regardless of how you submit your comments, you must include Docket No. NHTSA-2017-0069 on your comments. Note that all comments received, including any personal information provided, will be posted without change to http://www.regulations.gov, as described in the system of records notice

(DOT/ALL-14 FDMS), which can be reviewed at https://www.transportation.gov/privacy. Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comments, if submitted on behalf of an association, business, labor union, etc.). You may call the Docket Management Facility at 202-366-9826.

EPA will publish a Notice of Availability of this Draft EIS in the *Federal Register*. That notice will include a deadline by which comments on this Draft EIS must be received. NHTSA will simultaneously issue the Final EIS and Record of Decision (i.e., the final rule), pursuant to 49 U.S.C. § 304a(b) and DOT's *Final Guidance on MAP-21 Section 1319 Accelerated Decisionmaking in Environmental Reviews* (DOT 2014)[56] unless it is determined that statutory criteria or practicability considerations preclude simultaneous issuance.[57]

[56] Available at https://cms.dot.gov/sites/dot.gov/files/docs/MAP-21_1319_Final_Guidance.pdf.

[57] 42 U.S.C. § 4332a(b).

CHAPTER 2 PROPOSED ACTION AND ALTERNATIVES AND ANALYSIS METHODS

2.1 Introduction

NEPA requires that, when an agency prepares an EIS, it must evaluate the environmental impacts of its proposed action and alternatives to the proposed action.[1] An agency must rigorously explore and objectively evaluate all reasonable alternatives, including the alternative of taking no action. For alternatives that 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]

This chapter describes the Proposed Action and alternatives, explains the methods and assumptions applied in the analysis of environmental impacts, and summarizes environmental impacts in the following subsections:

- Section 2.2, *Proposed Action and Alternatives*
- Section 2.3, *Standard-Setting and EIS Methods and Assumptions*
- Section 2.4, *Resource Areas Affected and Types of Emissions*
- Section 2.5, *Comparison of Alternatives*

2.2 Proposed Action and Alternatives

NHTSA's Proposed Action is to set fuel economy standards for MY 2021–2026 passenger cars and light trucks (also referred to as the light-duty vehicle fleet) in accordance with Energy Policy and Conservation Act of 1975 (EPCA),[4] as amended by the Energy Independence and Security Act of 2007 (EISA).[5] Specifically, in addition to establishing new standards for MY 2022–2026 vehicles, NHTSA is also considering whether the current MY 2021 CAFE standards are "maximum feasible" and, if not, amending them as appropriate. In developing the Proposed Action and alternatives, NHTSA considered the four EPCA statutory factors that guide the agency's determination of maximum feasible standards: technological feasibility, economic practicability, the effect of other motor vehicle standards of the government on fuel economy, and the need of the United States to conserve energy.[6] In addition, NHTSA considered relevant safety and environmental factors.[7] During the process of developing proposed standards, NHTSA consulted with EPA and the U.S. Department of Energy (DOE) regarding a

[1] 40 CFR § 1502.14.

[2] 40 CFR § 1502.14(a), (d).

[3] 40 CFR § 1502.13. See City of Carmel-By-The-Sea v. U.S. Dept. of Transp., 123 F.3d 1142,1155 (9th Cir. 1997); City of Alexandria v. Slater, 198 F.3d 862, 867-69 (D.C. Cir. 1999), cert. denied sub nom., 531 U.S. 820 (2000).

[4] 49 U.S.C. § 32901 et seq.

[5] Pub. L. No. 110–140, 121 Stat. 1492 (Dec. 19, 2007).

[6] 49 U.S.C. § 32902(f).

[7] As noted in Chapter 1, NHTSA interprets the statutory factors as including environmental issues and permitting the consideration of other relevant societal issues, such as safety. *See*, e.g., *Competitive Enterprise Inst. v. NHTSA*, 956 F.2d 321, 322 (D.C. Cir. 1992) (citing *Competitive Enterprise Inst. v. NHTSA*, 901 F.2d 107, 120 n.11 (D.C. Cir. 1990)); and Average Fuel Economy Standards, Passenger Cars and Light Trucks; MYs 2011–2015, 73 FR 24352 (May 2, 2008).

variety of matters, as required by EPCA.[8] Consistent with CEQ NEPA implementing regulations, this EIS compares a reasonable range of action alternatives to the No Action Alternative (Alternative 0). This analysis assumes under the No Action Alternative that new MY 2021–2025 light-duty vehicles would comply with the current CAFE standards for MY 2021 and the augural CAFE standards for MYs 2022–2025, which NHTSA evaluated in the 2012 joint final rule, and that manufacturers would continue to comply with the MY 2025 augural CAFE standards indefinitely (Section 2.2.1, *Alternative 0: No Action Alternative*).[9] NHTSA is proposing Alternative 1 as the Preferred Alternative.

Under EPCA, as amended by EISA, NHTSA is required to set separate average fuel economy standards for passenger cars and light trucks. Because NHTSA intends to set standards both for cars and for trucks, and because evaluating the environmental impacts of this proposal requires consideration of the impacts of the standards for both vehicle classes, the main analyses presented in this EIS reflect the combined environmental impacts associated with the proposed standards for passenger cars and light trucks. In addition, Appendix D, *U.S. Passenger Car and Light Truck Results Reported Separately*, shows separate results for passenger cars and light trucks under each alternative.

2.2.1 Alternative 0: No Action Alternative

The No Action Alternative assumes that NHTSA would not amend the CAFE standards for MY 2021 passenger cars and light trucks. In addition, the No Action Alternative assumes that NHTSA would finalize the MY 2022–2025 augural CAFE standards that were described in the 2012 joint final rule. Finally, NHTSA assumes that the MY 2025 augural CAFE standards would continue indefinitely.

Currently, there are no enforceable CAFE standards for MY 2022 and beyond. However, the augural standards reflect where NHTSA last indicated it would set CAFE standards for MYs 2022–2025. In addition, this approach reflects NHTSA's most recent CAFE EIS analysis, where it assumed the augural standards for MYs 2022–2025 would be enforceable. Finally, these augural standards serve as a proxy for EPA's greenhouse gas (GHG) emission standards for MYs 2022–2025, which were finalized in the 2012 joint final rule. The NHTSA MY 2022–2025 augural CAFE standards were set in the 2012 joint final rule at levels that coordinated with the EPA MY 2022–2025 GHG emissions standards such that manufacturers would be able to build a single fleet that satisfies all requirements under both programs. Therefore, the No Action Alternative assumes that new MY 2022–2025 light-duty vehicles would be subject to the augural CAFE standards and that manufacturers would continue to be subject to the MY 2025 augural CAFE standards for MY 2026 and beyond. Although in the absence of any rulemaking activity the augural CAFE standards are not enforceable, consistent with public comments received on the scoping notice for this EIS (Chapter 1, *Purpose and Need for the Proposed Action*), NHTSA believes that they are the most appropriate baseline from which to analyze impacts in this EIS.

The No Action Alternative provides an analytical baseline against which to compare the environmental impacts of the other alternatives presented in the EIS.[10] NEPA expressly requires agencies to consider a

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[8] 49 U.S.C. § 32902(i).

[9] 40 CFR § 1502.14(d).

[10] 40 CFR §§ 1502.2(e), 1502.14(d). CEQ has explained that "[T]he regulations require the analysis of the no action alternative even if the agency is under a court order or legislative command to act. This analysis provides a benchmark, enabling decision makers to compare the magnitude of environmental effects of the action alternatives. [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. [40 CFR § 1500.1(a).]" Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations, 46 FR 18026 (Mar. 23, 1981).

‘‘no action’’ alternative in their NEPA analyses and to compare the impacts of not taking action with the impacts of action alternatives to demonstrate the environmental impacts of the action alternatives. The environmental impacts of the action alternatives are calculated in relation to the baseline of the No Action Alternative.

Table 2.2.1-1 shows the estimated average required fleet-wide fuel economy NHTSA forecasts under the No Action Alternative. The values reported in that table do not apply strictly to manufacturers in those model years. Both the augural MY 2022–2025 standards and the proposed standards are attribute-based standards based on vehicle footprint. Under the footprint-based standards, a curve defines a fuel economy performance target for each separate car or truck footprint. Using the curves, each manufacturer would therefore have a CAFE standard that is unique to each of its fleets, depending on the footprints and production volumes of the vehicle models produced by that manufacturer. A manufacturer would have separate footprint-based standards for cars and for trucks. Although a manufacturer’s fleet average standards could be estimated throughout the model year based on projected production volume of its vehicle fleet, the standards with which the manufacturer must comply would be based on its final model year production figures. A manufacturer’s calculation of its fleet average standards and its fleet’s average performance at the end of the model year would therefore be based on the production-weighted average target and performance of each model in its fleet. The values in Table 2.2.1-1 reflect NHTSA’s estimate based on application of the mathematical function defining the alternative (i.e., the curves that define the augural MY 2022–2025 CAFE standards) to the market forecast defining the estimated future fleets of new passenger cars and light trucks across all manufacturers. The fuel economy numbers presented here do not include a fuel economy adjustment factor to account for real-world driving conditions (see Section 2.2.4, *Gap Between Compliance Fuel Economy and Real-World Fuel Economy*, for more discussion about the difference between adjusted and unadjusted mile-per-gallon [mpg] values).

Table 2.2.1-1. No Action Alternative: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	45.5	47.7	49.9	52.2	54.7	54.7
Light trucks	33.3	34.9	36.6	38.3	40.1	40.1
Combined cars and trucks	39.0	40.8	42.7	44.7	46.8	46.7

mpg = miles per gallon

2.2.2 Action Alternatives

In addition to the No Action Alternative, NHTSA analyzed a range of action alternatives with fuel economy stringencies that increase, on average, 0.0 percent to 3.0 percent annually from either the MY 2020 or MY 2021 standards for passenger cars and light trucks. For purposes of its analysis, NHTSA assumes that the MY 2026 CAFE standards for each alternative would continue indefinitely. As NHTSA stated in the Notice of Intent to Prepare an EIS,[11] the agency believes that, based on the different ways

[11] Notice of Intent to Prepare an Environmental Impact Statement for Model Year 2022–2025 Corporate Average Fuel Economy Standards, 82 FR 34740 (July 26, 2017).

the agency could weigh EPCA's four statutory factors, the maximum feasible level of CAFE stringency falls within the range of alternatives under consideration.[12]

Throughout this EIS, estimated impacts are shown for eight action alternatives that illustrate the following range of average annual percentage increases in fuel economy for both passenger cars and light trucks:

- 0.0 percent annual average increase for both passenger cars and light trucks (Alternative 1—NHTSA's Preferred Alternative
- 0.5 percent average annual increase for both passenger cars and light trucks (Alternative 2 and Alternative 3)
- 1.0 percent average annual increase for passenger cars and a 2.0 percent annual average increase for light trucks for MYs 2021–2026 (Alternative 4)
- 1.0 percent average annual increase for passenger cars and a 2.0 percent annual average increase for light trucks for MYs 2022–2026 (Alternative 5)
- 2.0 percent annual average increase for passenger cars and a 3.0 percent annual average increase for light trucks for MYs 2021–2026 (Alternative 6 and Alternative 7)
- 2.0 percent annual average increase for passenger cars and a 3.0 percent annual average increase for light trucks for MYs 2022–2026 (Alternative 8)

In addition, some of the action alternatives (Alternative 3 and Alternative 7) would phase out air conditioning (AC) and off-cycle adjustments from MY 2022 through MY 2026. AC and off-cycle adjustments allow manufacturers to increase their calculated CAFE levels based on the application of technologies that improve AC efficiency or otherwise improve real-world fuel economy beyond levels calculated using standard EPA city and highway compliance test procedures. Additional alternate test procedures may be used to increase calculated CAFE levels by the amount attributable to these technologies. Examples of technologies for which manufacturers could use off-cycle adjustment procedures are solar reflective glass/glazing and solar reflective surface coating (paint), active grille shutters, and efficient air conditioning compressors. Under alternatives that phase out AC and off-cycle adjustments, manufacturers would have to apply other technologies to reach the same calculated CAFE levels, but NHTSA expects that manufacturers would not remove associated AC and off-cycle technologies. Therefore, applying additional technologies to reach the same calculated CAFE level is expected to result in lower fuel use and emissions compared to otherwise equivalent standards that allow AC and off-cycle adjustments. This impact is more pronounced after 2026 when the phasing out of AC and off-cycle adjustments is complete, which can result in different short-term versus long-term impacts when comparing action alternatives. In particular, while Alternative 8 fuel economy (mpg) requirements are higher than fuel economy requirements for Alternative 7 in 2021 through 2026, Alternative 7 would phase out AC and off-cycle adjustments and Alternative 8 would not phase out these adjustments. As a result, Alternative 7 is the action alternative with the lowest impact compared to the No Action Alternative in terms of fuel consumption and emissions through 2050 and beyond.

As noted, NHTSA reasonably believes the maximum feasible standards fall within the range of alternatives presented in this EIS. This range encompasses a spectrum of possible standards that NHTSA

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

could select, based on how the agency weighs EPCA's four statutory factors. By providing environmental analyses at discrete representative points, the decision-makers and the public can determine the environmental impacts of points that fall between those individual alternatives. The alternatives evaluated in this EIS therefore provide decision-makers with the ability to select from a wide variety of other potential alternatives with stringencies that would increase annually at average percentage rates from 0.0 to 3.0 percent, or up to the No Action Alternative. This range includes, for example, alternatives with stringencies that would increase at different rates for passenger cars and for light trucks and stringencies that would increase at different rates in different years.

For Alternative 3 and Alternative 7, Table 2.2.2-1 provides the proposed phase-out of the AC and off-cycle adjustments, with the caps applying separately for passenger cars and for light trucks.

Table 2.2.2-1. Proposed Air Conditioning Efficiency and Off-Cycle Adjustment Caps Phase-Out Schedule and Effects on Carbon Dioxide Emissions (grams/mile)

Adjustment	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Air Conditioning Efficiency Cap	6	5	4	3	2	0
Off-Cycle Cap	10	8	6	4	2	0

Tables for each of the action alternatives show estimated average required fuel economy levels reflecting application of the mathematical functions defining the alternatives to the market forecast defining the estimated future fleets of new passenger cars and light trucks across all manufacturers. The actual standards under the alternatives are footprint-based and each manufacturer would have a CAFE standard that is unique to each of its fleets, depending on the footprints and production volumes of the vehicle models produced by that manufacturer. Like Table 2.2.1-1 for the No Action Alternative, the required fuel economy values projected for each action alternative do not include a fuel economy adjustment factor to account for real-world driving conditions. (See Section 2.2.4, *Gap Between Compliance Fuel Economy and Real-World Fuel Economy,* for more discussion about the difference between adjusted and unadjusted fuel economy.)

This EIS assumes a weighted average of flexible fuel vehicles' fuel economy levels when operating on gasoline and on E85 (a blend of 15 percent gasoline and 85 percent ethanol, by volume). In particular, this EIS assumes that flexible fuel vehicles operate on gasoline 99 percent of the time and on E85 1 percent of the time.

2.2.2.1 Alternative 1 (Preferred Alternative): 0.0 Percent Annual Increase in Fuel Economy, MYs 2021–2026

Alternative 1 would require a 0.0 percent average annual fleet-wide increase in fuel economy for passenger cars and light trucks for MYs 2021–2026. This alternative revises the MY 2021 standards to the MY 2020 levels and carries those numbers forward for MYs 2022–2026. Alternative 1 is NHTSA's Preferred Alternative.[13] Table 2.2.2-2 lists the estimated average required fleet-wide fuel economy under Alternative 1.

[13] In this EIS, Alternative 1 is also sometimes referred to as NHTSA's Proposed Action.

Table 2.2.2-2. Alternative 1: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	43.7	43.7	43.7	43.7	43.7	43.7
Light trucks	31.3	31.3	31.3	31.3	31.3	31.3
Combined cars and trucks	36.9	36.9	36.9	37.0	37.0	37.0

mpg = miles per gallon

2.2.2.2 Alternative 2: 0.5 Percent Annual Increase in Fuel Economy, MYs 2021–2026

Alternative 2 would require a 0.5 percent average annual fleet-wide increase in fuel economy for passenger cars and light trucks for MYs 2021–2026. Table 2.2.2-3 lists the estimated average required fleet-wide fuel economy under Alternative 2.

Table 2.2.2-3. Alternative 2: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	43.9	44.1	44.3	44.5	44.8	45.0
Light trucks	31.4	31.6	31.7	31.9	32.0	32.2
Combined cars and trucks	37.1	37.3	37.5	37.7	37.9	38.1

mpg = miles per gallon

2.2.2.3 Alternative 3: 0.5 Percent Annual Increase in Fuel Economy, Phase Out of AC/Off-Cycle Adjustments, MYs 2021–2026

Alternative 3 would require a 0.5 percent average annual fleet-wide increase in fuel economy for passenger cars and light trucks for MYs 2021–2026. Unlike Alternative 2, Alternative 3 would phase out AC and off-cycle compliance adjustments beginning with MY 2022 and fully phase them out in MY 2026 through the application of a cap. Table 2.2.2-4 lists the estimated average required fleet-wide fuel economy under Alternative 3.

Table 2.2.2-4. Alternative 3: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	43.9	44.1	44.3	44.5	44.8	45.0
Light trucks	31.4	31.6	31.7	31.9	32.0	32.2
Combined cars and trucks	37.1	37.3	37.5	37.7	37.9	38.1

mpg = miles per gallon

2.2.2.4 Alternative 4: 1.0 Percent Annual Increase in Passenger Car, 2.0 Percent Annual Increase in Light Truck Fuel Economy, MYs 2021–2026

Alternative 4 would require a 1.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 2.0 percent average annual increase for light trucks for MYs 2021–2026. Table 2.2.2-5 lists the estimated average required fleet-wide fuel economy under Alternative 4.

Table 2.2.2-5. Alternative 4: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	44.1	44.5	45.0	45.5	45.9	46.4
Light trucks	31.9	32.6	33.2	33.9	34.6	35.3
Combined cars and trucks	37.5	38.1	38.7	39.3	39.9	40.6

mpg = miles per gallon

2.2.2.5 Alternative 5: 1.0 Percent Annual Increase in Passenger Car, 2.0 Percent Annual Increase in Light Truck Fuel Economy, MYs 2022–2026

Alternative 5 would require a 1.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 2.0 percent average annual increase for light trucks for MYs 2022–2026. This alternative would not revise the MY 2021 CAFE standards. Table 2.2.2-6 lists the estimated average required fleet-wide fuel economy under Alternative 5.

Table 2.2.2-6. Alternative 5: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	45.5	46.0	46.4	46.9	47.4	47.9
Light trucks	33.3	34.0	34.7	35.4	36.1	36.9
Combined cars and trucks	39.0	39.6	40.2	40.8	41.5	42.1

mpg = miles per gallon

2.2.2.6 Alternative 6: 2.0 Percent Annual Increase in Passenger Car, 3.0 Percent Annual Increase in Light Truck Fuel Economy, MYs 2021–2026

Alternative 6 would require a 2.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 3.0 percent average annual increase for light trucks for MYs 2021–2026. Table 2.2.2-7 lists the estimated average required fleet-wide fuel economy under Alternative 6.

Table 2.2.2-7. Alternative 6: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	44.5	45.5	46.4	47.3	48.3	49.3
Light trucks	32.2	33.2	34.3	35.3	36.4	37.5
Combined cars and trucks	37.9	38.9	39.9	40.9	42.0	43.1

mpg = miles per gallon

2.2.2.7 Alternative 7: 2.0 Percent Annual Increase in Passenger Car, 3.0 Percent Annual Increase in Light Truck Fuel Economy, Phase Out of AC/Off-Cycle Adjustments, MYs 2021–2026

Alternative 7 would require a 2.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 3.0 percent average annual increase for light trucks for MYs 2021–2026. Alternative 7 is similar to Alternative 3 in that it would phase out AC and off-cycle compliance adjustments beginning with MY 2022 and fully phase them out in MY 2026 through the application of a cap. Table 2.2.2-8 lists the estimated average required fleet-wide fuel economy under Alternative 7.

Table 2.2.2-8. Alternative 7: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	44.5	45.5	46.4	47.3	48.3	49.3
Light trucks	32.2	33.2	34.3	35.3	36.4	37.5
Combined cars and trucks	37.9	38.9	39.9	40.9	42.0	43.1

mpg = miles per gallon

2.2.2.8 Alternative 8: 2.0 Percent Annual Increase in Passenger Car, 3.0 Percent Annual Increase in Light Truck Fuel Economy, MYs 2022–2026

Alternative 8 would require a 2.0 percent average annual fleet-wide increase in fuel economy for passenger cars and a 3.0 percent average annual increase for light trucks for MYs 2022–2026. This alternative would not revise the MY 2021 CAFE standards. Table 2.2.2-9 lists the estimated average required fleet-wide fuel economy under Alternative 8.

Table 2.2.2-9. Alternative 8: Estimated Average Required U.S. Passenger Car and Light Truck Fleet-Wide Fuel Economy (mpg) by Model Year

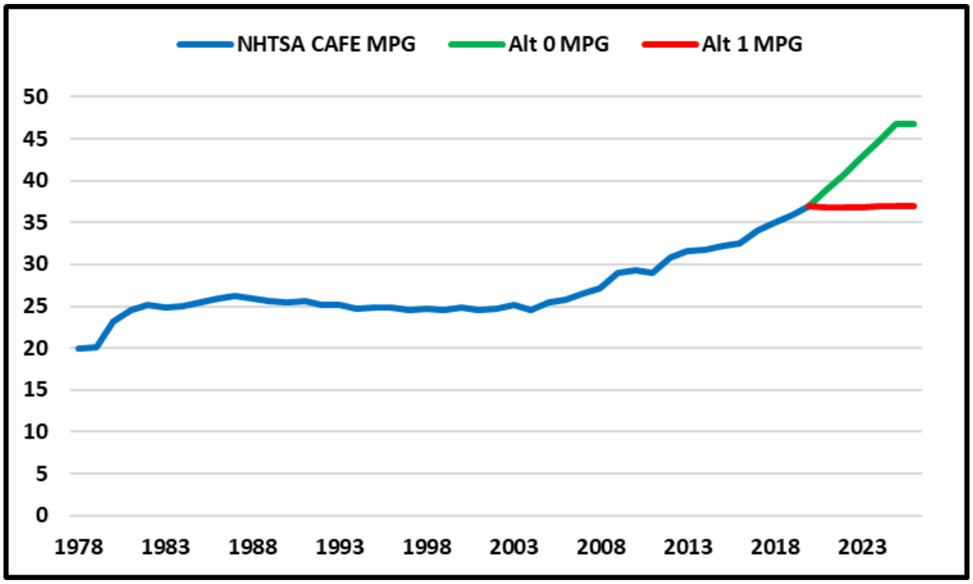
	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	45.5	46.4	47.4	48.4	49.4	50.4
Light trucks	33.3	34.4	35.4	36.5	37.6	38.8
Combined cars and trucks	39.0	40.0	41.0	42.1	43.2	44.3

mpg = miles per gallon

2.2.3 No Action and Action Alternatives in Historical Perspective

NHTSA has set CAFE standards since 1978. Figure 2.2.3-1 illustrates unadjusted[14] required CAFE fuel economy (mpg) for combined passenger cars and light trucks from 1978 through 2020 (EPA 2018a). The figure extends these fuel economy levels out to their required average fuel economy levels under Alternative 1 and the No Action Alternative (Alternative 0) to demonstrate the range of alternatives currently under consideration.

Figure 2.2.3-1. Historical CAFE Fuel Economy Requirements for Passenger Cars and Light Trucks through MY 2020 and Range of Projected EIS Alternative Standards through MY 2026



mpg = miles per gallon

As illustrated in the figure, light-duty vehicle fuel economy has moved through four phases since 1975: (1) a rapid increase from MYs 1975–1981, (2) a slower increase until MY 1987, (3) a gradual decrease until MY 2004, and (4) and a large increase since MY 2005. The MY 2018–2020 CAFE standards should extend this increase through 2020, and the MY 2021–2026 action alternatives would maintain or further increase fuel economy at historically high levels through 2026.

2.2.4 EPA's Proposed Carbon Dioxide Standards

In conjunction with NHTSA's Proposed Action, EPA has proposed amended or new carbon dioxide (CO_2) emissions standards under Section 202(a) of the Clean Air Act (CAA) for MYs 2021–2026. For increased harmonization with NHTSA's CAFE standards, EPA is also proposing to exclude air conditioning refrigerants and leakage, as well as nitrous oxide and methane emissions, for compliance with CO_2

[14] Unadjusted fuel economy measures fuel economy as achieved by vehicles in the laboratory. Adjusted fuel economy, reported in EPA window stickers, includes adjustments to better estimate actual achieved on-road fuel economy, and is generally lower than its corresponding unadjusted fuel economy values. Figure 2.2.3-1 uses historical unadjusted fuel economy data as a basis to compare projected achieved fuel economy (based on existing and proposed CAFE rules) because projected achieved fuel economy data would also be derived from laboratory testing and would not include an adjustment factor. See Section 2.2.4, *Gap between Compliance Fuel Economy and Real-World Fuel Economy,* for more discussion about the difference between NHTSA laboratory test fuel economy and EPA adjusted fuel economy.

standards after MY 2020.[15] The joint proposal represents a coordinated approach that would allow industry to build a single national fleet that would satisfy both the GHG requirements under the CAA and CAFE requirements under EPCA (as amended by EISA). Table 2.2.4-1 lists EPA's estimates of its projected overall fleet-wide CO_2 emissions compliance targets under the proposed standards, as stated in Section I of the Notice of Proposed Rulemaking (NPRM).

Table 2.2.4-1. Projected U.S. Passenger Car and Light-Truck Fleet-Wide Emissions Compliance Targets under the Proposed Carbon Dioxide Standards (grams/mile)

	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	MY 2026
Passenger cars	204	204	204	204	204	204
Light trucks	284	284	284	284	284	284
Combined cars and trucks	241	241	241	241	240	240

2.2.5 Gap between Compliance Fuel Economy and Real-World Fuel Economy

Real-world fuel economy levels achieved by light-duty vehicles in on-road driving are lower than the corresponding levels measured under the laboratory-like test conditions used to determine CAFE compliance. This is because the city and highway tests used for compliance do not encompass the range of driver behavior and climatic conditions experienced by typical U.S. drivers and because CAFE ratings include certain adjustments and flexibilities (EPA 2012b). CAFE ratings are based on laboratory test *drive cycles* for city and highway driving conditions, and they reflect a weighted average of 55 percent city and 45 percent highway conditions. Beginning in MY 1985, to bring new vehicle window labels closer to the on-road fuel economy that drivers actually achieve, EPA adjusted window-sticker fuel economy ratings downward by 10 percent for the city test and 22 percent for the highway test. Since MY 2008, EPA has based vehicle labels on a five-cycle method that includes three additional tests (reflecting high speed/high acceleration, hot temperature/air conditioning, and cold temperature operation) as well as a 9.5 percent downward fuel economy adjustment for other factors not reflected in the five-cycle protocol (EPA 2018a). While these changes are intended to better align new vehicle window labels with on-road fuel economy, CAFE standards and compliance testing are still determined using the two-cycle city and highway tests.[16]

For more discussion of the on-road fuel economy gap (the difference between adjusted and unadjusted mpg), see Section II.G.6 the NPRM.

2.2.6 Alternatives Considered but Not Analyzed in Detail

In response to NHTSA's Notice of Intent,[17] some commenters suggested an alternative that included an annual increase in CAFE standards of at least 7 percent. For the reasons set forth in the NPRM, NHTSA continues to believe that the maximum feasible level of increased stringency on average falls within the

[15] EPA is seeking public comment with regard to this change. For more information, please consult the NPRM.

[16] Except as noted, when fuel economy values are cited in this EIS, they represent standards compliance values. Real-world fuel economy levels are lower, and the environmental impacts are estimated based on real-world fuel economy rather than compliance ratings.

[17] Notice of Intent to Prepare an Environmental Impact Statement for Model Year 2022–2025 Corporate Average Fuel Economy Standards, 82 FR 34740 (July 26, 2017).

range of alternatives included in this EIS. Multiple individual commenters stated that the agency should consider an alternative that is more stringent than the MY 2022–2025 augural standards that NHTSA identified as maximum feasible in 2012, and others stated that the augural standards should be the lower bound of the reasonable range of alternatives in the NEPA analysis. NHTSA has not analyzed an alternative that represents CAFE standards that would be more stringent than the MY 2022–2025 augural standards for passenger cars and light trucks because the agency believes that such an alternative would, after a careful balancing of EPCA's four statutory factors, fall well outside the range of the maximum feasible level.

In addition, one commenter indicated that NHTSA should include as an alternative the MY 2021 standard as the lower end of the MY 2022–2025 CAFE standards. NHTSA considered in its Notice of Intent that the No Action Alternative would be continuing the current CAFE standards for MY 2021 indefinitely. However, based on comments received on the Notice of Intent, the agency's No Action Alternative instead is the augural MY 2022–2025 CAFE standards, which were included in the final rule issued in 2012. However, Alternative 1 would maintain the levels of the MY 2020 CAFE standards through MY 2026; the commenter's suggested alternative therefore falls within the range of alternatives considered in this EIS.

2.3 Standard-Setting and EIS Methods and Assumptions

Each of the alternatives represents a different manner in which NHTSA could conceivably balance conflicting policies and considerations in setting the standards. For example, the most stringent action alternative in terms of required mpg (Alternative 8), which would increase passenger car CAFE standards by 2 percent per year and light-truck CAFE standards by 3 percent per year, weighs energy conservation and climate change considerations more heavily and weighs economic practicability and safety less heavily. In contrast, the least stringent action alternative (Alternative 1) would increase both car and truck fuel economy standards on average by 0.0 percent per year, and it places more weight on economic practicability.

NHTSA has assessed the effectiveness and costs of technologies as well as market forecasts and economic assumptions for fuel economy standards, as described in the Section II of the NPRM and Chapters 6 and 8 of the Preliminary Regulatory Impact Analysis (PRIA). NHTSA uses a modeling system to assess the technologies that manufacturers could apply to their fleet to comply with each alternative. Section 2.3.1, *CAFE Model*, describes this model and its inputs and provides an overview of the analytical pieces and tools used in the analysis of alternatives.

2.3.1 CAFE Model

Since 2002, as part of its CAFE analyses, NHTSA has employed a modeling system developed specifically to help the agency apply technologies to thousands of vehicles and develop estimates of the costs and benefits of potential CAFE standards. The CAFE Compliance and Effects Modeling System developed by the Volpe National Transportation Systems Center, referred to as the CAFE model,[18] enables NHTSA to evaluate efficiently, systematically, and reproducibly many regulatory options. The CAFE model is designed to simulate compliance with a given set of CAFE standards for each manufacturer that sells vehicles in the United States. The model begins with a representation of the MY 2016 offerings for each

[18] NHTSA has also referred to this model as the *Volpe model* in other documentation.

manufacturer that includes the specific engines and transmissions on each model variant, observed sales volumes, and all fuel economy improvement technology already present on those vehicles. From there it adds technology, in response to the standards being considered, in a way that minimizes the cost of compliance and reflects many real-world constraints faced by automobile manufacturers. After simulating compliance, the model calculates the impacts of the simulated standard: technology costs, fuel usage and cost, emissions of air pollutants and GHGs, social costs and benefits, and safety impacts.

For this EIS, NHTSA used the CAFE model to estimate annual fuel consumption for each calendar year from 2021, when the Proposed Action and some alternatives would first take effect, through 2050, when almost all passenger cars and light trucks in use would have been manufactured and sold during or after the model years for which NHTSA would set CAFE standards in this action. This analysis reflects several changes made to the CAFE model since 2012, when NHTSA used the model to estimate the effects, costs, and benefits of final MY 2017–2021 CAFE standards and augural standards for MYs 2022–2025. A description of the key changes in the model since 2012, as well as a complete description of the software, is included in Section II of the NPRM as well as in separate model documentation located in NHTSA's docket for this rulemaking.

2.3.1.1 CAFE Model Inputs

The CAFE model requires estimates for the following types of inputs:

- A forecast of the future vehicle fleet.
- Availability, applicability, and incremental effectiveness and cost of fuel-saving technologies.
- Economic factors, including vehicle survival and mileage accumulation patterns, future fuel prices, the rebound effect (the increase in vehicle use that results from improved fuel economy), and the social cost of carbon.
- Fuel characteristics and vehicular emissions rates.
- Coefficients defining the shape and level of CAFE footprint-based curves, which use vehicle footprint (a vehicle's wheelbase multiplied by the vehicle's average track width) to determine the required fuel economy level or target.

NHTSA uses the model for analysis; the model makes no *a priori* assumptions regarding inputs such as fuel prices and available technologies and it does not dictate the stringency or form of the CAFE standards to be examined. NHTSA makes those selections based on the best currently available information and data.

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

For more information about the CAFE model and its inputs, see Section II of the NPRM and Chapter 6 of the PRIA. Model documentation, publicly available in the rulemaking docket and on NHTSA's website, explains how the model is installed, how the model inputs and outputs are structured, and how the model is used.

Although NHTSA has used the CAFE model as a tool to inform its consideration of potential CAFE standards, the CAFE model alone does not determine the CAFE standards NHTSA proposes or promulgates as final regulations. NHTSA considers the results of analyses using the CAFE model and external analyses, including this EIS and the analyses cited herein. NHTSA also considers consumer acceptance of new technologies and the extent to which changes in vehicle costs and fuel economy might affect vehicle production and sales. Using all this information, NHTSA considers the governing statutory factors, along with environmental issues and other relevant societal issues, such as safety, and promulgates the maximum feasible standards based on its best judgment on how to balance these factors.

Vehicle Fleet Forecast

To determine what levels of stringency are feasible in future model years, NHTSA must project what vehicles and technologies will exist in those model years and then evaluate which of those technologies can feasibly be applied to those vehicles to raise their fuel economy. The agency therefore establishes an analysis fleet representing those vehicles against which they can analyze potential future levels of stringency and their costs and benefits based on the best available information and a reasonable balancing of various policy concerns.

More information about the vehicle market forecast used in this EIS is available in Section II.B of the NPRM.

Technology Assumptions

The analysis of costs and benefits employed in the CAFE model reflects NHTSA's assessment of a broad range of technologies that can be applied to passenger cars and light trucks. The model considers technologies in four broad categories: engine, transmission, vehicle, and electrification/accessory and hybrid technologies. More information about the technology assumptions used in this EIS can be found in Section II.D of the NPRM and Chapter 6 of the PRIA. Table 2.3.1-1 lists the types of technologies considered in this analysis for improving fuel economy.

Table 2.3.1-1. Technologies Considered by the CAFE Model that Manufacturers Can Add to Their Vehicle Models and Platforms to Improve Fuel Economy

Engine Technologies	Transmission Technologies	Vehicle Technologies	Electrification/Accessory and Hybrid Technologies
Oil lubrication and friction reduction (three levels)	Manual six and seven-speed transmission	Low-rolling-resistance tires (three levels)	Electric power steering/electro-hydraulic power steering
Cylinder deactivation	Six, seven, eight, nine, and ten-speed automatic transmissions	Low-drag brakes	Improved accessories
Advanced cylinder deactivation	Advanced six, eight, and ten-speed automatic transmissions	Front or secondary axle disconnect for four-wheel drive systems	Air conditioner systems efficiency improvement
Variable valve timing	Six and eight speed dual clutch transmissions	Aerodynamic drag reduction (four levels)	12-volt stop-start
Variable valve lift	Continuous variable transmissions	Mass reduction (five levels)	48-volt belt integrated starter generator
Stoichiometric gasoline direct-injection technology	Advanced continuous variable transmissions	--	48-volt crank integrated started generator
Turbocharging and downsizing	--	--	Power split hybrids
Cooled exhaust-gas recirculation	--	--	P2 hybrids
Advanced diesel engines	--	--	Plug-in hybrid electric vehicles (30-mile and 50-mile range)
High-compression engines	--	--	Electric vehicles

Economic Assumptions

NHTSA's analysis of the energy savings, changes in emissions, and environmental impacts likely to result from the action alternatives relies on a range of forecasts, economic assumptions, and estimates of parameters used by the CAFE model. These economic values play a significant role in determining the impacts on fuel consumption, changes in emissions of criteria and toxic air pollutants and GHGs, and resulting economic costs and benefits of alternative standards. The CAFE model uses the following forecasts, assumptions, and parameters, which are described in Chapters 6 and 8 of the PRIA:

- Forecasts of sales of passenger cars and light trucks for MYs 2021–2026 in response to new vehicle prices that result from manufacturer's compliance actions.
- Assumptions about the fraction of the on-road fleet that remains in service at different ages, how rapidly average annual use of passenger cars and light trucks changes over time, and how passenger car and light truck use declines with increasing vehicle age.
- Assumptions about rates of retirement for older vehicles in response to new vehicle prices that result from manufacturer's compliance actions.
- Forecasts of fuel prices over the expected lifetimes of MY 2021–2026 passenger cars and light trucks.
- Forecasts of expected future growth in total passenger car and light-truck use, including vehicles of all model years in the U.S. vehicle fleet.
- The size of the gap between test and actual on-road fuel economy.
- The magnitude of the fuel economy rebound effect.
- Changes in emissions of criteria and toxic air pollutants and GHGs that result from saving each gallon of fuel and from each added mile of driving.
- The value of increased driving range and less frequent refueling that result from increases in fuel economy.
- The costs of increased congestion, traffic crashes, and noise caused by added passenger car and light-truck use.
- The costs of light-duty traffic fatalities resulting from changes to vehicle exposure, vehicle retirement rates, and reductions in vehicle mass to improve fuel economy.
- The discount rate applied to future benefits.

NHTSA's analysis includes several assumptions about how vehicles are used. For example, this analysis recognizes that passenger cars and light trucks typically remain in use for many years, so even though NHTSA proposes to regulate only passenger cars and light trucks through MY 2026, the changes in fuel use, emissions, and other environmental impacts will continue for many years beyond that. However, the contributions to these impacts by vehicles produced during a particular model year decline over time as those vehicles are gradually retired from service, while those that remain in use are driven progressively less as they age. The CAFE model defines vehicle lifetime as the point at which less than 2 percent of the vehicles originally produced in a model year remain in service.

NHTSA's analysis incorporates new modules in the CAFE model—a sales and scrappage module and a safety module—that affect the retirement of the existing vehicle population in response to changes in new vehicle prices, relative cost per mile, and the GDP growth rate. For example, the increase in the price of new vehicles as a result of manufacturers' compliance actions can result in increased demand for used vehicles, extending the expected age and lifetime vehicle miles travelled (VMT) of less efficient, more polluting, and, generally, less safe vehicles. Chapter 8 of the PRIA describes these modules in detail. The extended usage of older vehicles results in fewer gallons of fuel saved, greater air pollutant emissions, and more on-road fatalities under more stringent regulatory alternatives, which has important implications for the evaluation of economic costs and benefits of alternative standards. The modules assume that vehicles are operated for up to 40 years after their manufacture, after which no vehicles produced in that model year are included in the modeling.

In addition, NHTSA's analysis accounts for a rebound effect. Specifically, when the fuel economy of a vehicle increases, the cost of fuel consumed per mile driven decreases, thereby creating an incentive for additional vehicle use. Any increase in vehicle use would therefore offset part of the fuel savings that would otherwise result from higher fuel economy. The total passenger car and light-truck VMT would increase slightly because of the rebound effect, and tailpipe emissions of pollutants strictly related to vehicle use would increase in proportion to increased VMT. Conversely, when the fuel economy of a vehicle decreases, the cost of fuel consumed per mile driven increases, resulting in decreased vehicle use. In this EIS, the rebound effect for light-duty vehicles is an estimated 20 percent. These VMT impacts are reflected in the estimates of emissions under each of the alternatives evaluated (Section 2.4.1, *Types of Emissions*).

The impacts of the alternatives evaluated in this EIS reflect a specific combination of economic inputs in the CAFE model. Detailed descriptions of the sources of forecast information, the rationale underlying each economic assumption, and the agency's choices of specific parameter values are included in Chapter 8 of the PRIA.

Coefficients Defining the Shape and Level of CAFE Footprint-Based Curves

In the NPRM, NHTSA proposes CAFE standards for MYs 2021–2026 expressed as a mathematical function that defines a fuel economy target for each vehicle model and, for each fleet, establishes a required CAFE level determined by computing the sales-weighted harmonic average[19] of those targets. NHTSA describes its methods for developing the coefficients defining the curves for the Proposed Action in Section II.C of the NPRM.

2.3.2 Constrained versus Unconstrained CAFE Model Analysis

NHTSA's CAFE model results presented in the NPRM and PRIA differ slightly from those presented in this EIS. EPCA and EISA require that the Secretary determine the maximum feasible levels of CAFE standards in a manner that sets aside the potential use of CAFE credits or application of alternative fuels toward compliance with new standards. NEPA, however, does not impose such constraints on analysis; instead, its purpose is to ensure that "public officials make decisions that are based on [an] understanding of environmental consequences."[20] The EIS therefore presents results of an "unconstrained" analysis that considers manufacturers' potential use of CAFE credits and application of alternative fuels in order to disclose and allow consideration of the real-world environmental consequences of the Proposed Action and alternatives.

[19] The harmonic average is the reciprocal of the arithmetic mean of the reciprocals of the given set of observations and is generally used when averaging units like speed or other rates and ratios.

[20] 40 CFR § 1500.1(c).

2.3.3 Modeling Software

Table 2.3.3-1 provides information about the software that NHTSA used for computer simulation modeling of the projected vehicle fleet and its upstream and downstream emissions.

Table 2.3.3-1. Modeling Software

Model Title	Model Inputs	Model Outputs Used in this Analysis
DOE: NEMS (CAFE model uses projections based on 2017 AEO Reference Case due to the timing of CAFE modeling. The 2018 AEO Reference Case is used elsewhere in this EIS where information was taken directly from that document.)		
National Energy Modeling System	• Freeze fuel economy standards from 2021 onward • Other inputs are default values for the AEO 2017	• Projected fuel prices for all fuels • U.S. average electricity-generating mix for future years
Argonne National Laboratory : GREET (1 2017 Version) Fuel-Cycle Model		
Greenhouse Gases and Regulated Emissions in Transportation	• Estimates for nationwide average electricity generating mix estimate from NEMS 2017 Early Release • Other inputs are default GREET 2017 data	• Upstream emissions for EV electricity generation • Estimates of upstream emissions associated with production, transportation, and storage for gasoline, diesel, hydrogen and E85
EPA: MOVES (2014a)		
Motor Vehicle Emissions Simulator	• Emissions data from in-use chassis testing; remote sensing; state vehicle inspection and maintenance; and other programs	• NO_X, SO_X, CO, VOCs, PM2.5, and toxic emission factors (tailpipe, evaporative, brake and tire wear) for CAFE model for cars and light-duty trucks, for four fuel types: gasoline, diesel, hydrogen and E85
Volpe: CAFE Model (2018 Version)		
CAFE Compliance and Effects Model	• Characteristics of analysis 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 emission 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 size, criteria and toxic emissions (tons) for future years

Model Title	Model Inputs	Model Outputs Used in this Analysis
Joint Global Change Research Institute: GCAM RCP Scenario Results		
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 emission scenarios (baselines)
Brookhaven National Laboratory and Oak Ridge National Laboratory: CO2SYS (v.2.3)		
CO_2 System Calculations Model	• Atmospheric gas concentrations from MAGICC model output • Natural sea water observations prepared at the Scripps Institution of Oceanography • Constants from the CO2SYS model	• Projected ocean pH in 2040, 2060, and 2100 under GHG emission scenarios
National Center for Atmospheric Research: MAGICC6		
Model for the Assessment of Greenhouse-gas Induced Climate Change	• Adjusted GCAMReference, GCAM6.0, and RCP4.5 climate scenarios to reflect projected emissions from the car and light-duty vehicle fleet in the US from the action alternatives.	• Projected global CO_2 concentrations, global mean surface temperature from 2017 through 2100

[a] NEMS = National Energy Modeling System; AEO = Annual Energy Outlook; DOE = U.S. Department of Energy; GREET = Greenhouse Gases, Emissions, and Energy Use in Transportation; EV = electric vehicle; E85 = ethanol fuel blend of 85% denatured ethanol; EPA = U.S. Environmental Protection Agency; 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; RCP = representative concentration pathway; GHG = greenhouse gas; CO_2 = carbon dioxide

2.3.4 Energy Market Forecast Assumptions

In this EIS, NHTSA uses projections of energy consumption and supply derived from the U.S. Department of Energy (DOE) Energy Information Administration (EIA), which 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 (Annual Energy Outlook [AEO]) and the world (International Energy Outlook [IEO]). EIA reports energy forecasts through 2050 for consumption and supply by energy fuel source, sector, and geographic region. The model used to formulate EIA projections incorporates all federal and state laws and regulations in force at the time of modeling. Potential legislation and laws under debate in Congress are not included.

In this EIS, NHTSA's CAFE model uses projections of energy consumption and supply based on the 2017 AEO Reference Case due to the timing of when the CAFE modeling was performed. The 2018 AEO Reference Case is used elsewhere in this EIS where information was taken directly from that document. The AEO projections assume that NHTSA's and EPA's vehicle standards announced in the 2012 final rule, including both the MY 2017–2021 CAFE standards and the MY 2022–2025 augural CAFE standards, are fully enforced and that manufacturers generally comply with those standards. The AEO forecast further assumes that CAFE standards are held constant after MY 2025, with forecast fuel economy improvements after MY 2025 based on economic cost-benefit analysis from consumers' and manufacturers' perspectives, which does not include energy security and potential GHG emissions reduction benefits. NHTSA's CAFE requirements consider a cost-benefit assessment from a societal perspective, which includes energy security and potential GHG emissions reduction benefits.

2.3.5 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 the following elements in its NEPA document:[21]

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

In this EIS, NHTSA acknowledges incomplete, uncertain, or unavailable information where it is relevant to the agency's analysis of the potential environmental impacts of the alternatives. For example, NHTSA recognizes that scientific information about the potential environmental impacts of changes in emissions of CO_2 and associated changes in temperature, including those expected to result from the proposed rule, is uncertain and incomplete. NHTSA relies on the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC 2013a, 2013b, 2014b,) and the U.S. Global Change Research Program (GCRP) Fourth National Climate Assessment (GCRP 2017) as a recent "summary of existing credible scientific evidence which is relevant to evaluating the reasonably foreseeable significant adverse impacts on the human environment."[22] Some discussions, such as in Section 8.6.5, *Health, Societal, and Environmental Impacts of Climate Change*, address general potential effects of climate change, but these impacts are not attributable to any particular action, such as the Proposed Action and alternatives.

[21] 40 CFR § 1502.22(b).
[22] 40 CFR § 1502.22(b)(3).

2.4 Resource Areas Affected and Types of Emissions

The major resource areas affected by the action alternatives are energy, air quality, and climate. Chapter 3, *Energy*, describes the affected environment for energy and energy impacts under each alternative. Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, describe the affected environments and direct and indirect impacts for air quality and climate change, respectively. The action alternatives also would affect the following resource areas (although to a lesser degree than energy, air quality, and climate): land use and development, hazardous materials and regulated waste, historical and cultural resources, noise, and environmental justice. These resource areas are discussed in Chapter 7, *Other Impacts*. Chapter 8, *Cumulative Impacts*, describes the cumulative impacts of the action alternatives on all resource areas.

2.4.1 Types of Emissions

Emissions, including GHGs, criteria pollutants, and toxic air pollutants, are categorized for purposes of this analysis as either *downstream* or *upstream*. Downstream emissions are released from a vehicle while it is in operation, parked, or being refueled, and consist of tailpipe exhaust, evaporative emissions of volatile compounds from the vehicle's fuel storage and delivery system, and particulates generated by brake and tire wear. All downstream emissions were estimated using the most recent version of EPA's Motor Vehicle Emission Simulator (MOVES2014a) model (EPA 2017h). Upstream emissions related to the action alternatives are those associated with crude-petroleum extraction and transportation, and with the refining, storage, and distribution of transportation fuels. Upstream emissions from electric vehicles (EVs) also include emissions associated with using primary fuels (e.g., coal, natural gas, nuclear) to generate the electricity needed to run these vehicles. The amount of emissions created when generating electricity depends on the composition of fuels used for generation, which varies regionally. NHTSA estimated both domestic and international upstream emissions of CO_2 and domestic upstream emissions of criteria air pollutants and toxic air pollutants. Estimates of all upstream emissions were based on the Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET, version 2017) model developed by the DOE Argonne National Laboratory (ANL 2002). Section 2.4.1.1, *Downstream Emissions*, and Section 2.4.1.2, *Upstream Emissions*, describe analytical methods and assumptions used in this EIS for emissions modeling, including the impact of the rebound effect. Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, discuss modeling issues related specifically to the air quality and climate change analyses, respectively.

2.4.1.1 Downstream Emissions

Most downstream emissions are exhaust (tailpipe) emissions. The basic method used to estimate tailpipe emissions entails multiplying the estimated total miles driven by cars and light trucks of each model year and age by their estimated emission rates per vehicle-mile of each pollutant. These emission rates differ between cars and light trucks, between gasoline and diesel vehicles, and by age. With the exception of sulfur dioxide (SO_2), NHTSA and EPA calculated the increase in emissions of these criteria pollutants from added car and light truck use by multiplying the estimated increases in vehicle use during each year over their expected lifetimes by per-mile emission rates appropriate to each vehicle type, fuel used, model year, and age as of that future year.

The CAFE model uses emission factors developed by EPA using the most recent version of the Motor Vehicle Emission Simulator (MOVES2014a) (EPA 2017h). MOVES2014a incorporates EPA's updated estimates of real-world emissions from passenger cars and light trucks and accounts for emission control requirements on exhaust emissions and evaporative emissions, including the Tier 2 Vehicle & Gasoline Sulfur Program (EPA 2011) and the mobile source air toxics (MSAT) rule (EPA 2007). The MOVES2014a database includes default distributions of vehicles by type and age, vehicle activity levels, vehicle characteristics, national-level fuel quality estimates, and other key parameters used to generate emission estimates. In modeling downstream emissions of particulate matter 2.5 microns or less in diameter (PM2.5), EPA included emissions from brake and tire wear in addition to exhaust. MOVES2014a defaults were used for all other parameters to estimate tailpipe and other components of downstream emissions under the No Action Alternative.

NHTSA's and EPA's emissions analysis method assumes that no reduction in tailpipe emissions of criteria pollutants or toxic air pollutants will occur solely as a consequence of improvements in fuel economy that are not already accounted for in MOVES2014a. In its emissions calculations, MOVES2014a accounts for power required of the engine under different operating conditions, such as vehicle weight, speed, and acceleration. Changes to the vehicle that result in reduced engine load, such as from more efficient drivetrain components, improved aerodynamics, and lower rolling-resistance tires, are therefore already reflected in the MOVES2014a calculations of both fuel economy and emissions. Because the proposed standards are not intended to dictate the design and technology choices manufacturers must make to comply, a manufacturer could employ technologies that increase fuel economy (and therefore reduce CO_2 and SO_2 emissions) while at the same time increasing emissions of other criteria pollutants or toxic air pollutants, as long as the manufacturer's production still meets both the fuel economy standards and prevailing EPA emission standards. Depending on which strategies are pursued to meet the increased fuel economy standards, emissions of these other pollutants could increase or decrease.

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

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

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

Almost all of the carbon in fuels that are combusted in vehicle engines is oxidized to CO_2, and essentially all of the sulfur content of the fuel is oxidized to SO_2. As a result, emissions of CO_2 and SO_2 are constant in terms of grams emitted per gallon of fuel; their total emissions vary directly with the total volume of fuel used, and inversely with fuel economy (mpg). Therefore, emission factors for CO_2 and SO_2 are not constant in terms of grams emitted per VMT of a specific vehicle, because fuel economy—and 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 emission controls with which a vehicle is equipped.[23] For other criteria pollutants and toxic air pollutants, MOVES2014a

[23] The CAFE model's new sales and scrappage module accounts for the deferred retirement of older vehicles as a result of changes in new vehicle prices. Higher new vehicle prices due to more stringent CAFE standards would result in increased demand for used vehicles, which would result in higher levels of downstream criteria and toxic air pollutant emissions than otherwise anticipated without accounting for this effect.

calculates emission rates individually for specific combinations of inputs, including various vehicle types, fuels, ages, and other key parameters as noted previously.

Emission factors in the MOVES2014a database are expressed in the form of grams per vehicle-hour of operation. To convert these emission factors to grams per mile, MOVES2014a was run for the year 2050, and was programmed to report aggregate emissions from vehicle start, running, brake and tire wear, and crankcase exhaust operations. EPA selected 2050 in order to generate emission factors that were representative of lifetime average emission rates for vehicles meeting the Tier 3 emission standard.[24] Separate estimates were developed for each vehicle type and model year, as well as for each state and month, in order to reflect the effects of regional and temporal variation in temperature and other relevant variables on emissions.

The MOVES2014a emissions estimates were then summed to the model year level and divided by total distance traveled by vehicles of that model year in order to produce per-mile emission factors for each pollutant. The resulting emission rates represent average values across the nation, and incorporate typical variation in temperature and other operating conditions affecting emissions over an entire calendar year.[25] These national average rates also reflect county-specific differences in fuel composition, as well as in the presence and type of vehicle inspection and maintenance programs.[26]

Emission rates for the criteria pollutant SO_2 were calculated by using average fuel sulfur content estimates supplied by EPA, together with the simplifying assumption that the entire sulfur content of fuel is emitted in the form of SO_2. These calculations assumed that national average gasoline and diesel sulfur levels would remain at current levels,[27] because there are currently no open regulatory actions to change those levels. Therefore, unlike many emissions of other criteria pollutants that are affected by exhaust after-treatment devices (e.g., a catalytic converter), sulfur dioxide emissions from vehicle use (in terms of emissions per VMT) decline in proportion to the decrease in fuel consumption.

The agencies assume that, as a result of the rebound effect, total VMT would increase slightly with increases in fuel economy, thereby causing tailpipe emissions of each air pollutant generated by vehicle use (rather than by fuel consumption) to increase in proportion to this increase in VMT. However, emissions on a per-VMT basis as calculated by MOVES2014a could decline because of increased fuel

[24] Because all light-duty emission rates in MOVES2014a are assumed invariant after MY 2022, a calendar-year 2050 run produced a full set of emission rates that reflect anticipated deterioration in the effectiveness of vehicles' emission control systems with increasing age and accumulated mileage for post-MY 2022 vehicles.

[25] The emission rates calculated by EPA for this analysis using MOVES2014a include only those components of emissions expected to vary in response to changes in vehicle use. These include exhaust emissions associated with starting and operating vehicles, and particulate emissions resulting from brake and tire wear. However, they *exclude* emissions associated with activities such as vehicle storage, because those do not vary directly with vehicle use. Therefore, the estimates of aggregate emissions reported for the No Action Alternative and action alternatives do not represent total emissions of each pollutant under any of those alternatives. However, the difference in emissions of each pollutant between any action alternative and the No Action Alternative does represent the agency's best estimate of the change in total emissions of that pollutant that would result from adopting that action alternative.

[26] The national mix of fuel types includes county-level market shares of conventional and reformulated gasoline, as well as county-level variation in sulfur content, ethanol fractions, and other fuel properties. Inspection and maintenance programs at the county level account for detailed program design elements such as test type, inspection frequency, and program coverage by vehicle type and age.

[27] These are 30 and 15 parts per million (ppm, measured on a mass basis) for gasoline and diesel respectively, which produces emission rates of 0.17 gram of SO_2 per gallon of gasoline and 0.10 gram per gallon of diesel.

economy, as discussed above.[28] If the increases in fuel consumption and emissions associated with the higher VMT (due to the rebound effect) are small compared to the decrease in fuel use (due to increased fuel economy), then the net result can be a reduction in total emissions.

2.4.1.2 Upstream Emissions

NHTSA also estimated the impacts of the action alternatives on upstream emissions associated with petroleum extraction and transportation, and the refining, storage, and distribution of transportation fuels, as well as upstream emissions associated with generation of electricity used to power EVs. When average fuel economy improves, NHTSA anticipates reductions in upstream emissions from fuel production and distribution, because the total amount of fuel used by passenger cars and light trucks would decline. To the extent that any action alternative would lead to an increase in use of EVs, upstream emissions associated with charging EVs could increase because of adopting that alternative. These increases would offset part of the reduction in upstream emissions resulting from reduced production of motor vehicle fuels. The net effect on national upstream emissions would depend on the relative magnitudes of the reductions in motor fuel production and the increases in electric power production, and would vary by pollutant. (See Section 6.2, *Energy Sources*, for a discussion of emissions differences between conventional vehicles and EVs).

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

The National Energy Modeling System (NEMS) is an energy-economy modeling system from the EIA. For the CAFE model analyses presented throughout this EIS, NHTSA used the NEMS AEO 2017 version to project the U.S. average electricity-generating fuel mix (e.g., coal, natural gas, and petroleum) for the reference year 2020 and used the GREET model (2017 version) (ANL 2017) to estimate upstream emissions. The analysis assumed that the vehicles would be sold and operated (refueled or charged) during the 2017 to 2060 timeframe. The analysis presented throughout this EIS assumes that the future EV fleet would charge from a grid whose mix is uniform across the country. As with gasoline, diesel, and E85, emission factors for electricity were calculated in 5-year increments from 1985 to 2050 in GREET to account for projected changes in the national grid mix. GREET contains information on the intensities (amount of pollutant emitted per unit of electrical energy generated) that extend to 2040.

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

For the action alternatives in this EIS, NHTSA assumed that increased fuel economy affects upstream emissions by causing decreases in the volumes of gasoline and diesel produced and consumed,[29] and by causing changes in emissions related to electricity generation due to the different EV deployment levels projected under each action alternative. NHTSA calculated the impacts of decreased fuel production on total emissions of each pollutant using the volumes of petroleum-based fuels estimated to be produced and consumed under each action alternative, together with emission factors for individual phases of the fuel production and distribution process derived from GREET. The emission factors derived from GREET (expressed as grams of pollutant per million British thermal units of fuel energy content) for each phase of the fuel production and distribution process were multiplied by the volumes of different types of fuel produced and distributed under each action alternative to estimate the resulting changes in emissions during each phase of fuel production and distribution. These emissions were added together to 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 from each action alternative was estimated as the difference between upstream emissions of that pollutant under the action alternative and its upstream emissions under the No Action Alternative.

2.5 Comparison of Alternatives

The CEQ NEPA implementing regulations direct federal agencies to present in an EIS "the environmental impacts of the proposal and the alternatives in comparative form, thus sharply defining the issues and providing a clear basis for choice among options by the decision-maker and the public." NHTSA has presented the environmental impacts of the alternatives in comparative form through each of the substantive chapters that follow in this EIS. To supplement that information, this section summarizes and compares the direct, indirect, and cumulative impacts of all the alternatives on energy, air quality, and climate, as presented in Chapter 3, *Energy*, Chapter 4, *Air Quality*, Chapter 5, *Greenhouse Gas Emissions and Climate Change*, and Chapter 8, *Cumulative Impacts*. No quantifiable, alternative-specific impacts were identified for the other resource areas discussed in Chapters 6, *Life-Cycle Assessment of Vehicle Energy, Material, and Technology Impact*s, and Chapter 7, *Other Impacts*, so they are not summarized here.

Under the alternatives analyzed in this EIS, fuel economy is expected to improve compared to current levels under each action alternative, more than offsetting the growth in the number of passenger cars and light trucks in use throughout the United States and in the annual VMT by these vehicles. This would result in projected decreases in total fuel consumption by passenger cars and light trucks compared to current conditions. Because CO_2 emissions are a direct consequence of total fuel consumption, the same result is projected for total CO_2 emissions from passenger cars and light trucks. However, NHTSA estimates that the proposed CAFE standards and each of the action alternatives would increase fuel consumption and CO_2 emissions from the future levels that would otherwise occur under the No Action Alternative.

2.5.1 Direct and Indirect Impacts

This section compares the direct and indirect impacts of the No Action Alternative and the eight action alternatives on energy, air quality, and climate (Table 2.5.1-1). Under NEPA, direct impacts "are caused

[29] NHTSA assumed that the proportions of total fuel production and consumption represented by ethanol and other renewable fuels (such as biodiesel) under each of the action alternatives would be identical to those under the No Action Alternative.

by the action and occur at the same time and place."[30] Indirect impacts "are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable."[31] For detailed discussions of the assumptions and methods used to estimate the direct and indirect impacts, see Section 2.3, *Standard-Setting and EIS Assumptions*, Section 3.4, *Environmental Impacts* (energy), Section 4.1.2, *Methods*, (air quality), and Section 5.3, *Analysis Methods* (climate). Table 2.5.1-1 summarizes the direct and indirect impacts on each resource.

2.5.2 Cumulative Impacts

Table 2.5.2-2 summarizes the cumulative impacts of the action alternatives on energy, air quality, and climate, as presented in Chapter 8, *Cumulative Impacts*.

[30] 40 CFR § 1508.8.

[31] Ibid.

Table 2.5.2-1. Direct and Indirect Impacts

Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Energy: Combined U.S. Passenger Car and Light Truck Fuel Consumption for 2020–2050 (billion gallons)								
2,878	3,084	3,071	3,059	3,036	2,997	2,973	2,935	2,948
Energy: Combined U.S. Passenger Car and Light Truck Increase in Fuel Consumption for 2020–2050 (billion gallons)								
--	206	192	181	158	119	95	56	69
Air Quality: Criteria Air Pollutant Emissions Changes in 2035								
--	Decrease: CO and NO_X. Increase: PM2.5, SO_2, and VOCs.	Decrease: CO and NO_X, less than Alt. 1. Increase: PM2.5, SO_2, and VOCs, less than Alt. 1.	Decrease: CO and NO_X, less than Alts. 1 and 2. Increase: PM2.5, SO_2, and VOCs, less than Alt. 1.	Decrease: CO and NO_X, less than Alts. 1 through 3. Increase: PM2.5, SO_2, and VOCs, less than Alts. 1 through 3.	Decrease: CO, less than Alts. 1 through 4. Increase: NO_X, more than Alts. 1 through 4. PM2.5, SO_2, and VOCs, less than Alts. 1 through 4.	Decrease: CO and NO_X, less than Alts. 1 through 5. Increase: PM2.5, SO_2, and VOCs, less than Alts. 1 through 5.	Decrease: CO and NO_X, generally less than Alts. 1 through 6. Increase: PM2.5, SO_2, and VOCs, less than Alts. 1 through 6.	Decrease: CO, generally less than Alts. 1 through 7. Increase: NO_X, generally more than Alts. 1 through 7. PM2.5, SO_2, and VOCs, less than Alts. 1 through 7.
Air Quality: Toxic Air Pollutant Emissions Changes in 2035								
--	Decrease: acetaldehyde, acrolein, 1,3-butadiene, benzene, and formaldehyde. Increase: DPM.	Decrease: acetaldehyde, acrolein, 1,3-butadiene, benzene, and formaldehyde, less than Alt. 1. Increase: DPM, less than Alt. 1.	Decrease: acetaldehyde, acrolein, 1,3-butadiene, benzene, and formaldehyde, less than Alts. 1 and 2. Increase: DPM, less than Alts. 1 and 2.	Decrease: acetaldehyde, acrolein, 1,3-butadiene, benzene, and formaldehyde, less than Alts. 1 through 3. Increase: DPM, less than under Alts. 1 through 3.	Decrease: acetaldehyde, acrolein, 1,3-butadiene, benzene, and formaldehyde, less than Alts. 1 through 4. Increase: DPM, less than Alts. 1 through 4.	Decrease: acetaldehyde, acrolein, 1,3-butadiene, benzene, and formaldehyde, less than Alts. 1 through 5. Increase: DPM, less than Alts. 1 through 5.	Decrease: acetaldehyde, acrolein, 1,3-butadiene, benzene, and formaldehyde, less than Alts. 1 through 6. Increase: DPM, less than Alts. 1 through 6.	Decrease: acetaldehyde, acrolein, 1,3-butadiene, benzene, and formaldehyde, less than Alts. 1 through 6, more than Alt. 7. Increase: DPM, less than Alts. 1 through 6, more than Alt. 7.

Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Air Quality: Increases in Premature Mortality Cases and Work-Loss Days in 2035								
--	Premature mortality: 86–194 cases Work-loss: 10,892 days	Premature mortality: 80–179 cases Work-loss: 10,094 days	Premature mortality: 75–169 cases Work-loss: 9,521 days	Premature mortality: 64–145 cases Work-loss: 8,144 days	Premature mortality: 48–109 cases Work-loss: 6,118 days	Premature mortality: 35–78 cases Work-loss: 4,398 days	Premature mortality: 18–40 cases Work-loss: 2,247 days	Premature mortality: 24–55 cases Work-loss: 3,080 days
Climate: Total Greenhouse Gas Emissions from U.S. Passenger Cars and Light Trucks for 2021–2100 ($MMTCO_2$)								
77,800	85,100	84,700	84,200	83,400	82,000	81,000	79,600	80,200
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)								
789.11	789.76	789.72	789.68	789.60	789.48	789.40	789.27	789.32
Climate Increase in Global Mean Surface Temperature by 2100 in °C (°F)								
3.484°C (6.271°F)	3.487°C (6.276°F)	3.487°C (6.276°F)	3.486°C (6.276°F)	3.486°C (6.275°F)	3.486°C (6.274°F)	3.485°C (6.273°F)	3.485°C (6.272°F)	3.485°C (6.273°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)								
76.28 (30.03)	76.34 (30.05)	76.33 (30.05)	76.33 (30.05)	76.32 (30.05)	76.31 (30.04)	76.31 (30.04)	76.30 (30.04)	76.30 (30.04)
Climate: Global Mean Precipitation Increase by 2100								
5.85%	5.86%	5.86%	5.86%	5.86%	5.86%	5.86%	5.85%	5.85%
Climate: Ocean Acidification in 2100 (pH)								
8.2176	8.2173	8.2173	8.2173	8.2173	8.2174	8.2174	8.2175	8.2175

Note: The numbers in this table have been rounded for presentation purposes. Therefore, the reductions might not reflect the exact difference of the values in all cases.
°C = degrees Celsius; °F = degrees Fahrenheit; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons of carbon dioxide; NO_X = nitrogen oxides; PM2.5 = particulate matter 2.5 microns in diameter or less; ppm = parts per million; SO_2 = sulfur dioxide; VOC = volatile organic compound

Table 2.5.2-2. Cumulative Impacts

Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Energy: Total Combined Gasoline, Diesel, Biofuel and Electricity Fuel Consumption by All U.S. Cars and Light Trucks for 2020–2050								
Fuel consumption could change due to a recent Presidential Executive Order on Promoting Energy Independence and Economic Growth (EO 13783, issued March 28, 2017) that could substantively affect energy supply. In addition, recent market trends indicate that global EV market share targets and quotas and associated manufacturer investments to improve EV technologies and increase the scale of EV manufacturing may affect U.S. transportation sector fuel use in the future.								
Energy: Total Change in Fuel Use by All U.S. Cars and Light Trucks for 2020–2050								
The magnitude and direction of reasonably foreseeable cumulative impacts cannot be quantified with precision.								
Air Quality: Criteria Air Pollutant (CO, NO_X, PM2.5, SO_2, and VOCs) Emissions Changes for 2018–2050								
Under all alternatives, cumulative impacts on air quality from criteria pollutants could increase or decrease depending on trends in the electric power sector, growth in EV usage, and potential changes in emissions standards and regulations for stationary and mobile sources.								
Air Quality: Toxic Air Pollutant (Acetaldehyde, Acrolein, Benzene, 1,3-Butadiene, DPM, and Formaldehyde) Emissions Changes for 2018–2050								
Under all alternatives, cumulative impacts on air quality from toxic air pollutants could increase or decrease depending on trends in the electric power sector, growth in EV usage, and potential changes in emissions standards and regulations for stationary and mobile sources.								
Air Quality: Changes in Premature Mortality Cases and Work-Loss Days in 2035 (Values within Range Depend on Assumptions Used)								
Under all alternatives, cumulative impacts on human health, as indicated by changes in premature mortality cases and work-loss days, could increase or decrease depending on trends in the electric power sector, growth in EV usage, and potential changes in emissions standards and regulations for stationary and mobile sources.								
Climate: Total Greenhouse Gas Emissions from U.S. Passenger Cars and Light Trucks for 2021–2100 ($MMTCO_2$)[1]								
77,800	85,100	84,700	84,200	83,400	82,000	81,000	79,600	80,200
Climate: Atmospheric Carbon Dioxide Concentrations in 2100 (ppm)								
687.29	687.90	687.87	687.83	687.76	687.64	687.56	687.44	687.49
Climate Increase in Global Mean Surface Temperature by 2100 in °C (°F)								
2.838°C (5.108°F)	2.841°C (5.113°F)	2.841°C (5.113°F)	2.840°C (5.113°F)	2.840°C (5.112°F)	2.840°C (5.111°F)	2.839°C (5.111°F)	2.839°C (5.110°F)	2.839°C (5.110°F)
Climate: Global Sea-Level Rise by 2100 in centimeters (inches)								
70.22 (27.65)	70.28 (27.67)	70.28 (27.67)	70.28 (27.67)	70.27 (27.67)	70.26 (27.66)	70.25 (27.66)	70.24 (27.65)	70.24 (27.66)
Climate: Global Mean Precipitation Increase by 2100								
4.77%	4.77%	4.77%	4.77%	4.77%	4.77%	4.77%	4.77%	4.77%
Climate: Ocean pH in 2100								
8.2723	8.2719	8.2719	8.2720	8.2720	8.2721	8.2721	8.2722	8.2722

[1]Total greenhouse gas emissions from U.S. passenger cars and light trucks are the same as in the direct and indirect impacts analysis. However, results differ for atmospheric CO_2 concentrations, surface temperature, sea-level rise, precipitation, and ocean pH. These differences are due to the fact that the cumulative impacts analysis uses a medium-high global emissions scenario (GCAM6.0) as opposed to the high emissions scenario (GCAM Reference Scenario) used in the direct and indirect impacts analysis. NHTSA chose the GCAM 6.0 scenario as a plausible global emissions baseline for the cumulative analysis, as this scenario is more aligned with reasonably foreseeable global actions that will result in a moderate level of emission reductions (although it does not explicitly include any particular policy or program).

EV = electric vehicles; CO = carbon monoxide; NO_X = nitrogen oxides; PM2.5 = particulate matter 2.5 microns in diameter or less; SO_2 = sulfur dioxide; VOC = volatile organic compound; DPM = diesel particulate matter; $MMTCO_2$ = million metric tons of carbon dioxide; °C = degrees Celsius; °F = degrees Fahrenheit; DPM = diesel particulate matter

CHAPTER 3 ENERGY

NHTSA's light-duty vehicle standards regulate fuel economy and thereby affect U.S. transportation fuel consumption. The *Annual Energy Outlook* (AEO) 2018 forecasts that transportation fuel will account for 70.4 percent of U.S. petroleum consumption in 2040 (EIA 2018a).[1] Improvements in vehicle fuel economy, combined with increases in U.S. petroleum production, have substantially reduced U.S. oil imports, the overall U.S. trade deficit, and U.S. vulnerability to foreign oil supply disruptions. Transportation fuel also accounts for a large portion of total U.S. energy consumption and has a significant impact on the overall balance of U.S. energy supply and demand. The AEO 2018 forecasts that the United States will become a net energy exporter starting in 2021, as net petroleum imports fall and net exports of coal and natural gas increase. The last time the United States was a net energy exporter was in 1952 (EIA 2017f).

The AEO 2018 forecast reflects enacted legislation and final regulations, including the NHTSA CAFE standards and greenhouse gas emissions standards for U.S. passenger cars and light trucks that were published in 2012.[2] The NHTSA 2012 EIS for the CAFE standards addressed impacts of fuel economy standards for MYs 2017–2021 and the augural standards set forth for MYs 2022–2025. Fuel economy standards for MYs 2022–2025 were not finalized in that 2012 rule, but it was assumed for purposes of analysis in the 2012 EIS that the values set forth for MYs 2022–2025 would be required in the future. The NHTSA EIS referred to CAFE "standards" for the full MY 2017–2025 period, coordinated and harmonized with EPA standards for greenhouse gas emissions in MYs 2017–2025, but the EIS noted that CAFE standards for MYs 2022–2025 would be determined in a subsequent rulemaking.

This chapter examines the energy impacts of the Proposed Action and alternatives that may revise the MY 2021 CAFE standards and would establish required CAFE standards for MYs 2022–2026. For the purpose of this analysis, the impacts of the Proposed Action and alternatives are measured relative to a No Action Alternative that assumes that manufacturers would comply with the augural MY 2022–2025 standards (Chapter 2, Section 2.1, *Proposed Action and Alternatives*). In light of the important role of the transportation sector in overall U.S. energy supply and demand, this chapter discusses past, present, and forecast U.S. energy production and consumption by sector and source to characterize the affected energy environment. This chapter also quantifies energy impacts under the Proposed Action and alternatives in relation to the No Action Alternative. The chapter is organized as follows:

- **Section 3.1, *Energy Intensity*,** describes past and forecast trends in U.S. energy intensity. The section addresses how these trends have changed the relationship between U.S. energy use and economic growth trends.
- **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). The section addresses how the passenger cars and light trucks vehicle sector affects overall energy use.
- **Section 3.3, *Petroleum Imports and U.S. Energy Security*,** describes how improving the fuel efficiency of vehicles and increasing energy production together affect U.S. energy security by

[1] This chapter uses 2040 as NHTSA's analysis year because it is sufficiently far in the future to have almost the entire light-duty vehicle fleet composed of MY 2026 or later vehicles.

[2] 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).

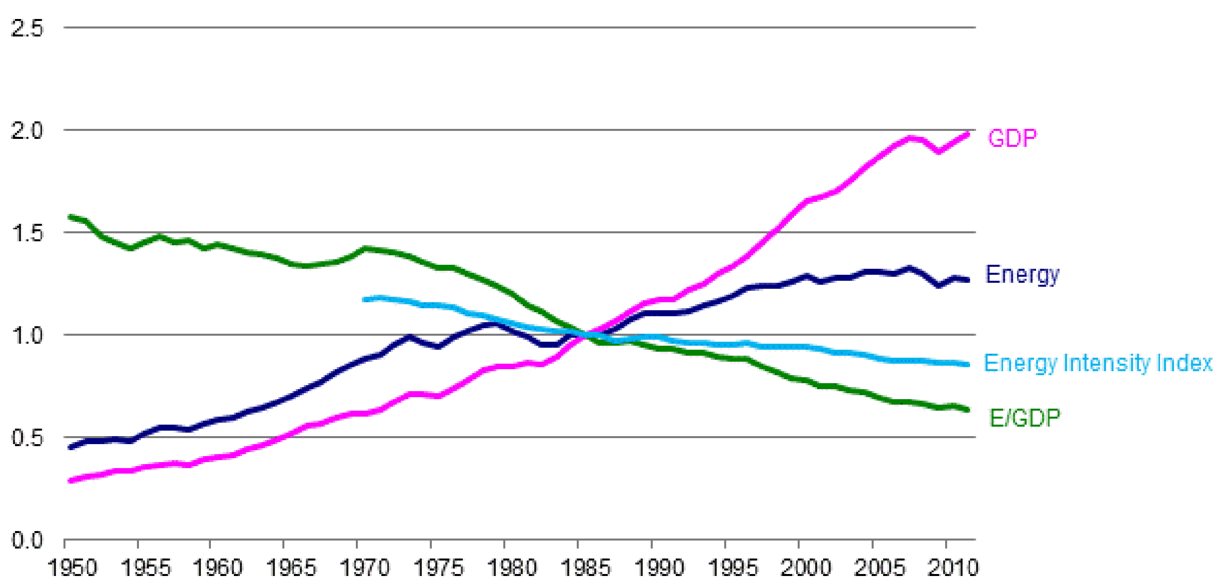
reducing the overall U.S. trade deficit and the macroeconomic vulnerability of the United States to foreign oil supply disruptions.

- **Section 3.4, *Environmental Consequences*,** describes the direct and indirect energy impacts of the Proposed Action and alternatives.

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 decreasing percentage of GDP from energy-intensive manufacturing). The U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy 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 index fell by 14 percent from 1985 to 2011, as the E/GDP ratio fell 36 percent, illustrating that the decline in energy use per dollar of GDP has come from energy efficiency improvements and shifts in the composition of GDP. The AEO 2018 forecasts ongoing declines in U.S. energy intensity, with the E/GDP forecast of energy intensity falling 34 percent from 2016 through 2040 (EIA 2018a). This forecast reflects energy efficiency improvements in all sectors of the U.S. economy, including among passenger cars and light trucks.

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



Source: DOE 2018a
GDP = gross domestic product; E/GDP = energy-GDP ratio

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

3.2 Affected Environment

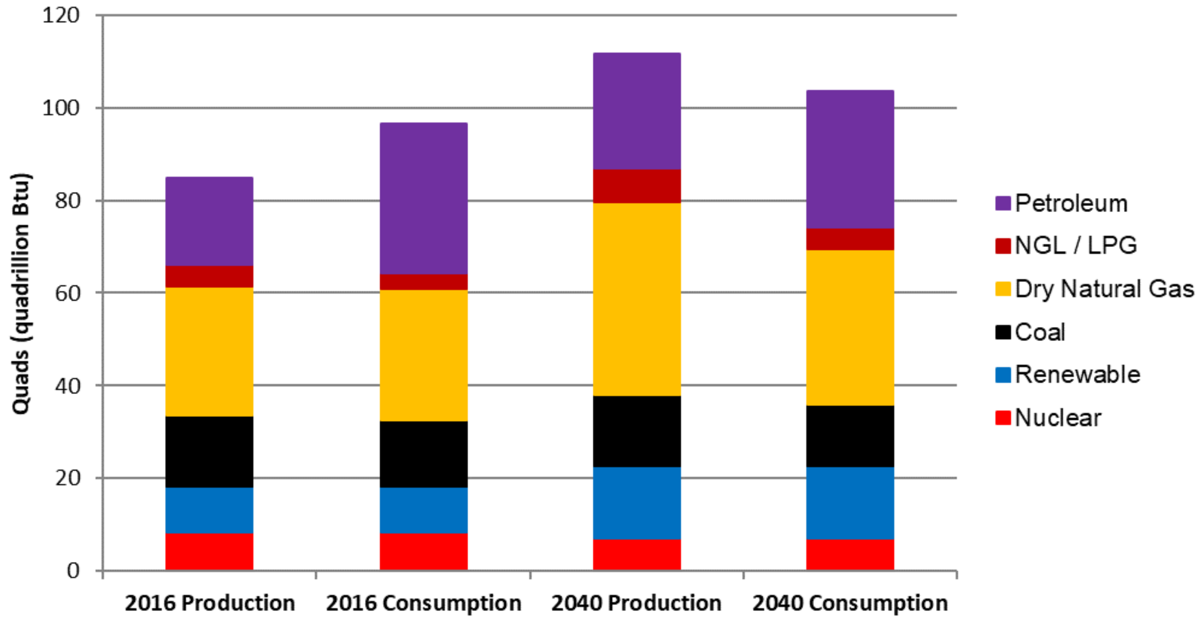
Although petroleum is overwhelmingly the primary source of energy for passenger cars and light trucks, these vehicles can use other fuels (e.g., electricity and natural gas). The Proposed Action and alternatives would affect demand for these fuels and thereby affect the availability and use of fuels consumed by other economic sectors. Understanding how primary fuel markets are expected to evolve in the coming years also provides context for considering energy impacts of the Proposed Action and alternatives. 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, *U.S. Production and Consumption of Primary Fuels*, discusses U.S. energy production and consumption by primary fuel source (petroleum, coal, natural gas, and other). Section 3.2.2, *U.S. Energy Consumption by Sector*, discusses U.S. energy consumption by stationary and transportation sectors.

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 [LPG] for consumption). These five energy sources accounted for 90 percent of U.S. energy consumption in 2016, whereas hydropower, biomass, solar, wind, and other renewable energy accounted for 10 percent of U.S. energy consumption in 2016 (EIA 2018a).

By 2040, the top five aforementioned energy sources are forecast to account for 85 percent of U.S. energy consumption, a reduction of 5 percent from their previous share, while the share of energy from renewable sources is forecast to rise to 15 percent (EIA 2018a). Forecast gains in U.S. oil and natural gas production, additional electricity generation from renewables, and energy efficiency improvements are expected to make the United States a net energy exporter starting in 2021. The change in U.S. energy production and consumption from 2016 through 2040 is shown in Figure 3.2.1-1.

Figure 3.2.1-1. U.S. Energy Production and Consumption by Source in 2016 and 2040



Source: EIA 2018a
Btu = British thermal unit; NGL = natural gas liquid; LPG = liquefied petroleum gas

From 2016 to 2040, production and consumption of nuclear power is forecast to decrease from 8.4 to 7.0 quadrillion Btu (quads), and production and consumption of renewable fuel is forecast to increase from 9.9 quads in 2016 to 15.7 quads in 2040. The forecast growth in renewable energy includes an increase in hydropower production and consumption from 2.5 quads in 2016 to 2.7 quads in 2040. EIA also projects 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 7.4 quads in 2016 to 13.0 quads in 2040. Electric power generation accounts for 67 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.[3] These fuels supplied 19 percent of U.S. energy consumption in 2016, and their combined share of consumption is forecast to increase to 22 percent by 2040.

[3] There are virtually no U.S. net imports of nuclear power in the sense that U.S. consumption of electricity generated by nuclear power is supplied by U.S. nuclear power plants. Supply and consumption of nuclear fuel at different stages of processing is more complex, encompassing a nuclear fuel cycle that includes mining of uranium ore, conversion into uranium hexafluoride (UF6), and enrichment to increase the concentration of uranium-235. Uranium quantities are expressed in the unit of measure U3O8e (equivalent). U3O8e is uranium oxide (or uranium concentrate) and the equivalent uranium-component of UF6 and enriched uranium. U.S. nuclear plants in 2015 purchased 94 percent of their total delivered U3O8e (equivalent) from foreign suppliers (EIA 2016d).

U.S. coal production is forecast to be unchanged at 15.3 quads in 2016 and in 2040, as coal consumption is expected to decline from 14.2 quads in 2016 to 13.1 quads in 2040.[4] The United States is currently, and is expected to remain, a net exporter of coal energy through 2040.

U.S. production of dry natural gas (separated from natural gas liquids, discussed below) is forecast to increase from 27.9 quads in 2016 to 41.6 quads in 2040, while consumption of natural gas is expected to rise from 28.5 quads in 2016 to 33.6 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 have enabled increases in U.S. shale gas production that far more than offset declines in conventional natural gas production.

Production of natural gas liquid (a similar but heavier hydrocarbon than dry natural gas) is forecast to increase from 4.7 quads in 2016 to 7.3 quads in 2040. After extraction, natural gas liquid is separated from dry natural gas in processing plants and sold as ethane, propane, and other LPGs. LPG consumption is forecast to increase from 3.3 quads in 2016 to 4.7 quads in 2040. Therefore, the increase in LPG production is expected to outpace the growth in LPG consumption, resulting in net exports from 2016 through 2040.

U.S. production of crude oil is forecast to increase from 18.6 quads in 2016 to 24.7 quads in 2040. Crude oil is refined into petroleum products (which includes gasoline and diesel, but excludes non-petroleum liquid fuels, such as biofuels and LPG). U.S. consumption of petroleum is forecast to decline from 32.3 quads in 2016 to 29.5 quads in 2040. Therefore, U.S. net imports of petroleum are forecast to decline from 13.7 quads (2.37 billion barrels) in 2016 to 4.8 quads (0.83 billion barrels) in 2040.

The primary fuel projections 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 natural gas liquid from 2017 through 2040. U.S. net imports of petroleum are also expected to decline to a level that is less than net exports of other primary fuels, resulting in a forecast of net energy exports from 2021 through 2040 (EIA 2018a).

3.2.2 U.S. Energy Consumption by Sector

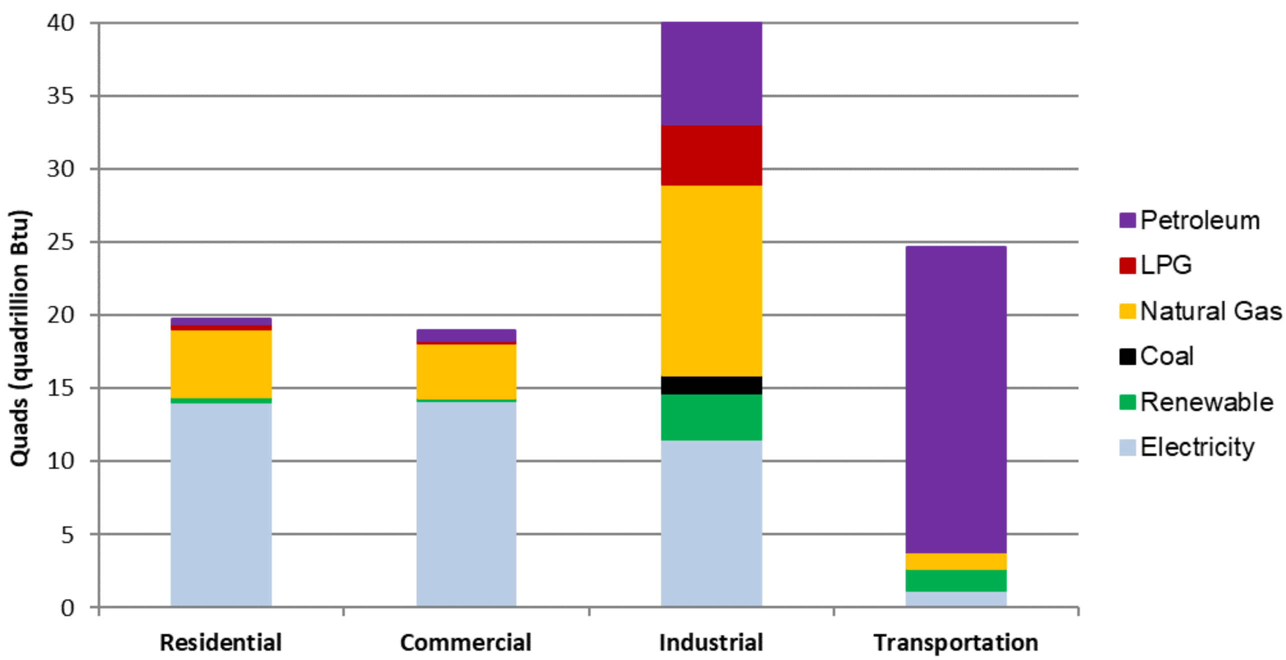
This section discusses the use of primary fuels by sector. Energy consumption occurs in four broad economic sectors: industrial, residential, commercial, and transportation. These sectors can be categorized as stationary (industrial, residential, and commercial sectors) or mobile (transportation). Stationary and transportation sectors consume the primary fuels previously described (e.g., natural gas, 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 38.0 quads in 2016 to 40.9 quads in 2040. In 2016, nuclear power supplied 22 percent of electric power generation source fuel, coal 34 percent, natural gas 27 percent, and renewable energy 15 percent. In 2040, nuclear power is expected to supply 17 percent of electric power generation source fuel, coal 29 percent, natural gas 27 percent,

[4] In early 2017, President Trump issued Executive Order 13783, *Promoting Energy Independence and Growth*. Exec. Order No. 13783, 82 FR 16093 (Mar. 31, 2017). This EO instructed executive agencies to review all existing regulations, orders, guidance documents, policies, and similar agency actions "that potentially burden the development or use of domestically produced energy resources, with particular attention to oil, natural gas, coal, and nuclear energy resources." This review would culminate in recommendations and actions that, to the extent permitted by law, "could alleviate or eliminate aspects of agency actions that burden domestic energy production." Based on these actions, future EIA forecasts may be revised significantly.

and renewable energy 26 percent. The petroleum share of electric power fuel supply is anticipated to decline from 0.7 percent in 2016 to just 0.3 percent in 2040 (EIA 2018a).

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, *Stationary-Sector Fuel Consumption*, and 3.2.2.2, *Transportation-Sector Fuel Consumption*, discuss the specifics of fuel use by those sectors, respectively.

Figure 3.2.2-1. Forecast U.S. Energy Consumption by End-Use Sector and Source Fuel in 2040



Source: EIA 2018a
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, which could be affected either by increased use of plug-in electric vehicles or by changes in upstream energy use related to energy production, refining, storage, and distribution. Because forecast deployment rates of plug-in electric vehicles are anticipated to be low and upstream energy use related to energy production, refining, storage, and distribution constitute only a small percentage of national energy consumption, the Proposed Action and alternatives would likely have a negligible impact on this sector. Section 3.2.2.2, *Transportation-Sector Fuel Consumption*, discusses transportation fuel consumption, on which the Proposed Action and alternatives 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 94 percent of 2016 energy use and 95 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 62 percent of

2016 industrial sector energy use, and account for 61 percent of forecast 2040 energy use. New energy technologies that 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 decline from 20.1 quads in 2016 to 19.7 quads in 2040, with this sector accounting for 21 percent of U.S. energy consumption in 2016 and 19 percent of 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 2016 to 0.6 quad in 2040. Residential use of natural gas is expected to increase from 4.5 quads in 2016 to 4.7 quads in 2040. Residential electricity use is expected to decline from 14.4 quads in 2016 to 14.1 quads in 2040, and renewable fuel use (primarily wood for heating) is expected to fall from 0.34 quad in 2016 to 0.30 quad in 2040.

Commercial-sector energy consumption is forecast to rise from 18.2 quads in 2016 to 18.9 quads in 2040, with this sector accounting for 19 percent of U.S. energy consumption in 2016 and 18 percent of forecast U.S. energy consumption in 2040. Commercial use of liquid fuel, renewable energy, and coal, are all expected to be essentially the same in 2016 and 2040, at 0.9 quad for liquid fuel, 0.1 quad for renewable energy, and 0.03 quad for coal. Commercial use of electricity is expected to increase from 13.9 quads in 2016 to 14.2 quads in 2040. Commercial use of natural gas is expected to increase from 3.2 quads in 2016 to 3.7 quads in 2040.

Industrial-sector energy consumption is projected to rise from 30.8 quads in 2016 to 40.0 quads in 2040, with this sector accounting for 32 percent of U.S. energy consumption in 2016 and 39 percent of forecast energy consumption in 2040. Industrial consumption of LPG is expected to increase from 2.7 quads in 2016 to 4.1 quads in 2040, petrochemical feedstock consumption is forecast to increase from 0.6 quad in 2016 to 1.3 quads in 2040, and other petroleum product liquid fuel use is expected to increase from 4.8 quads in 2016 to 5.7 quads in 2040. Industrial coal use is expected to increase from 1.1 quads in 2016 to 1.2 quads in 2040. Industrial consumption of renewable energy is expected to increase from 2.3 quads in 2016 to 3.2 quads in 2040. Industrial electricity use is forecast to increase from 9.6 quads in 2016 to 11.5 quads in 2040, and natural gas consumption is forecast to increase from 9.7 quads in 2016 to 13.0 quads in 2040.

3.2.2.2 Transportation-Sector Fuel Consumption

Transportation sector fuel consumption is forecast to decline from 27.7 quads in 2016 to 24.6 quads in 2040. In 2016, petroleum supplied 91.3 percent of transportation energy use, biofuel (mostly ethanol used in gasoline blending) 5.5 percent, natural gas 2.8 percent, LPG (propane) 0.03 percent, and electricity 0.37 percent. In 2040, petroleum is expected to supply 84.4 percent of transportation energy use, biofuel 6.1 percent, natural gas 4.5 percent, hydrogen 0.18 percent (up from 0.002 percent in 2015), LPG 0.06 percent, and electricity 4.6 percent.

In 2016, passenger cars and light trucks accounted for 56 percent of transportation energy consumption, medium- and heavy-duty (HD) vehicles accounted for 24 percent, air travel accounted for 8 percent, and other transportation (e.g., boats, rail, pipeline) accounted for 12 percent. In 2040, passenger cars and light trucks are expected to account for 44 percent of transportation energy consumption, HD vehicles 27 percent, air travel 14 percent, and other transportation 15 percent. The forecast decline in the percentage of transportation energy used by passenger cars and light trucks reflects the fuel economy improvements that are expected under the No Action Alternative.

In 2016, the transportation sector accounted for 78.2 percent of total U.S. petroleum consumption. In 2040, transportation is expected to account for 70.4 percent of U.S. petroleum use, with the industrial sector accounting for 22.3 percent. The residential and commercial sectors and electricity generation combined are expected to account for just 3.6 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 70.4 percent of U.S. petroleum use in 2040, U.S. net petroleum imports through 2040 are expected to result primarily from fuel consumption by the transportation sector.

The forecast decline in transportation energy use is led by a 31.4 percent forecast decline from 2016 to 2040 in energy used by passenger cars and light trucks, despite a 12.4 percent forecast increase in vehicle miles travelled (VMT) by passenger cars and light trucks. The forecast decline in energy use by passenger cars and light trucks reflects the impacts under the No Action Alternative. The EPA greenhouse gas emissions standards and NHTSA CAFE standards in the 2018 AEO forecast (and, thus, the No Action Alternative) result in a 63.6 percent forecast increase from 2016 to 2040 in the average miles per gallon achieved by all passenger cars and light trucks in use, as older, less efficient vehicles are replaced by more efficient vehicles.[5] The forecast decline in energy use by passenger cars and light trucks is reflected in a 31.4 percent forecast decline from 2016 to 2040 in transportation sector gasoline use, with gasoline expected to account for 80 percent of energy consumption by passenger cars and light trucks in 2040.

The AEO 2018 also forecasts a 0.9 percent decline from 2016 to 2040 in energy used by HD vehicles despite a 28 percent forecast increase in VMT for HD trucks, reflecting impacts of Phase 1 and Phase 2 standards for HD vehicle fuel efficiency. The small forecast decline in energy used by HD vehicles is associated with a 5.7 percent forecast decline from 2016 to 2040 in transportation sector diesel use, with diesel expected to account for 77.4 percent of HD vehicle fuel in 2040.

3.3 Petroleum Imports and U.S. Energy Security

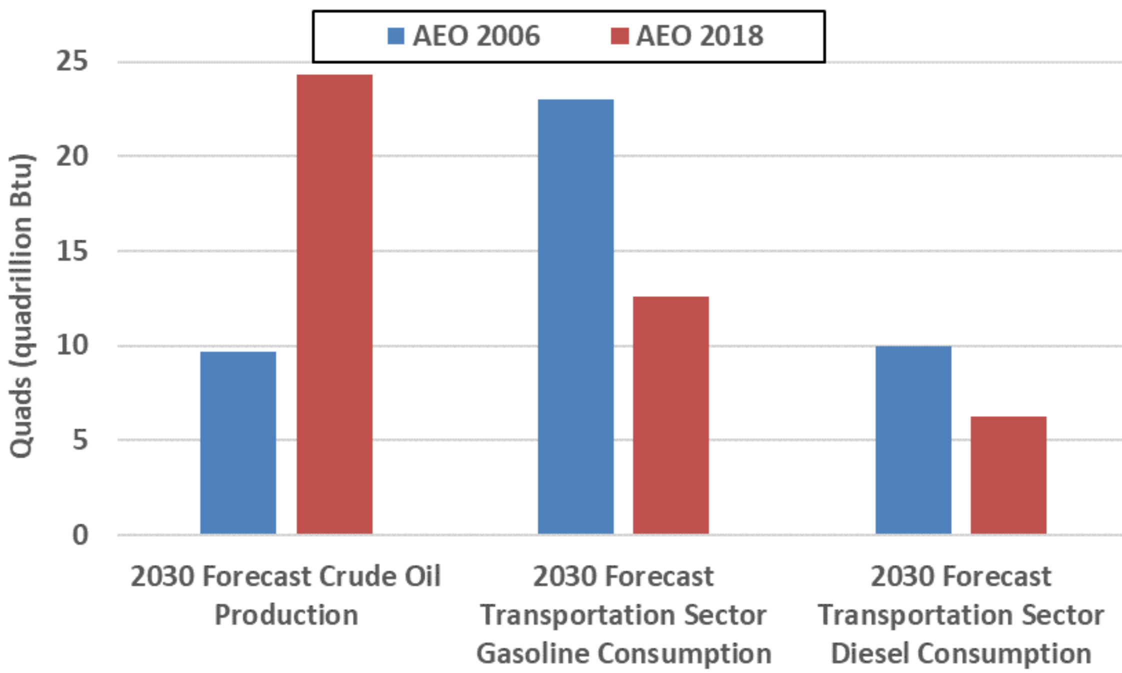
Section 3.2, *Affected Environment,* shows that the United States is expected to have net energy exports from 2017 through 2040 for the combination of all source fuels, except for petroleum. Petroleum net imports are also expected to decline to a level that is less than net exports of other primary fuels, resulting in U.S. net energy exports from 2021 through 2040. In 2040, the transportation sector is expected to account for 70.4 percent of all U.S. petroleum use, with passenger cars and light trucks accounting for 44 percent of transportation energy consumption. Therefore, fuel economy improvements required by previously promulgated CAFE standards for passenger cars and light trucks have had a substantial impact on the forecast extent of U.S. dependence on petroleum imports.

The forecast decline in U.S. net petroleum imports reflects stark changes in forecasts for both petroleum production and transportation sector petroleum consumption between the time of the AEO 2006 and the AEO 2018, as shown in Figure 3.3-1. The AEO 2006 forecast U.S. crude oil production of 9.7 quads in 2030, but the AEO 2018 forecasts production of 22.0 quads in 2030, an increase of 14.6 quads. The AEO 2006 also forecast transportation sector gasoline consumption of 23.0 quads and diesel consumption of

[5] The 2018 AEO forecast generally assumes fleet-wide compliance with the EPA GHG standards and NHTSA CAFE standards (including the augural standards). However, for the reasons provided in the Notice of Proposed Rulemaking (NPRM) and Preliminary Regulatory Impact Analysis (PRIA), new information since the promulgation of those rules in 2012 indicates that manufacturers may not be able to achieve those fuel economy targets. Thus, there remains some level of uncertainty with regard to the 2018 AEO forecast, although it remains the best available source of information with regard to future energy markets.

10.0 quads in 2030, but the AEO 2018 forecasts transportation sector gasoline consumption of 12.6 quads and diesel consumption of 6.2 quads in 2030, a decrease of 14.1 quads. (Figure 3.3-1 compares forecasts for 2030 because this was the last year of the AEO 2006 forecast.)

Figure 3.3-1. Changes in 2030 Annual Energy Outlook Forecasts with Large Impacts on U.S. Net Petroleum Imports

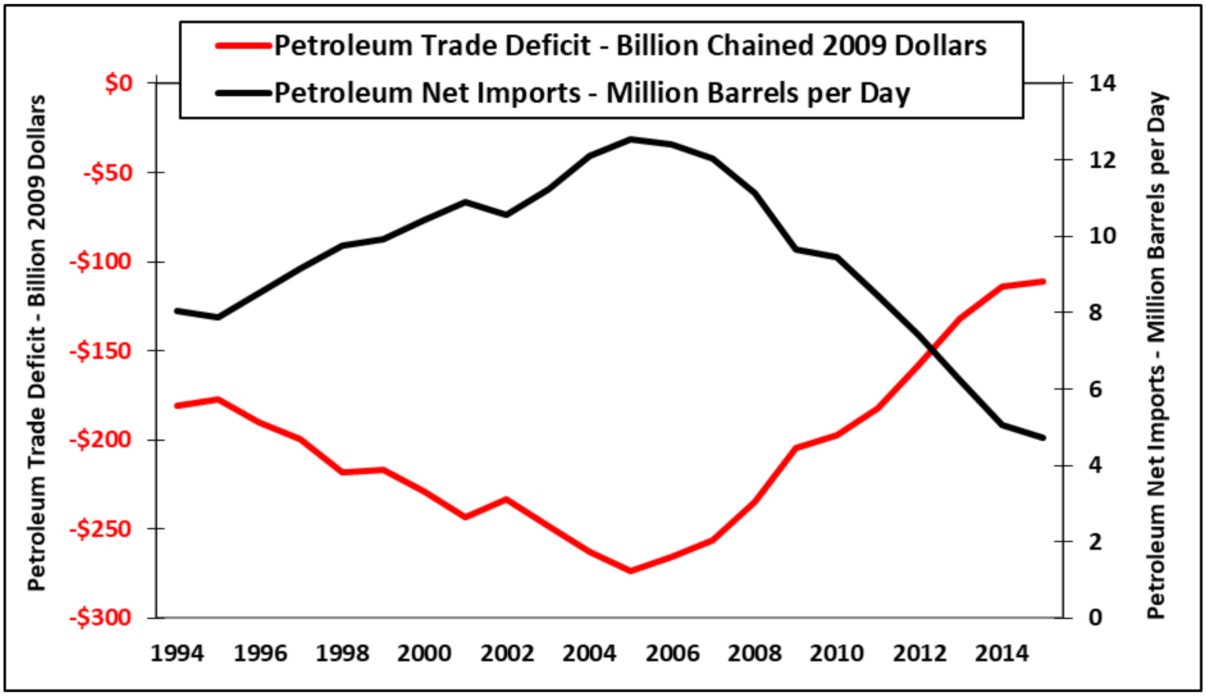


Source: EIA 2006 and EIA 2018a
AEO = Annual Energy Outlook; Btu = British thermal unit

As noted in Section 3.2, *Affected Environment,* the forecast trend in diesel use is mostly associated with HD vehicles, and the forecast trend in gasoline use is mostly associated with passenger cars and light trucks. About half of the difference between AEO 2006 and AEO 2018 forecasts for gasoline and diesel use in 2030 reflects slower forecast growth in VMT, while improvements in vehicle efficiency account for the other half of this change. The AEO 2018 also forecasts another 9.3 percent fall in gasoline use from 2030 to 2040 (a decline of 1.2 quads) as older vehicles are replaced by more efficient passenger cars and light trucks. Furthermore, the change in the gasoline forecast from AEO 2006 to AEO 2018 understates the decline in petroleum used in gasoline because the amount of petroleum consumed has been reduced by ethanol blending. 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.

Figure 3.3-2 shows the 1994–2015 rise and fall of U.S. net imports of petroleum (in million barrels per day) and the associated trend in the U.S. petroleum trade deficit (in billion dollars per year). The petroleum trade deficit reflects the physical volume of petroleum net imports and the prevailing price of crude oil that determines the dollar value of petroleum net imports. However, Figure 3.3-2 shows that the petroleum trade deficit trend (in 2009 chained dollars) has been a near mirror image of the petroleum net import trend despite changes in oil prices from 1994 to 2015. From 2000 through 2005 the U.S. petroleum trade deficit accounted for almost 40 percent of the total U.S. trade deficit, but the petroleum trade deficit declined from $273 billion in 2005 to $111 billion in 2015, as petroleum net imports fell from 12.5 million barrels per day in 2005 to 4.7 million barrels per day in 2015.

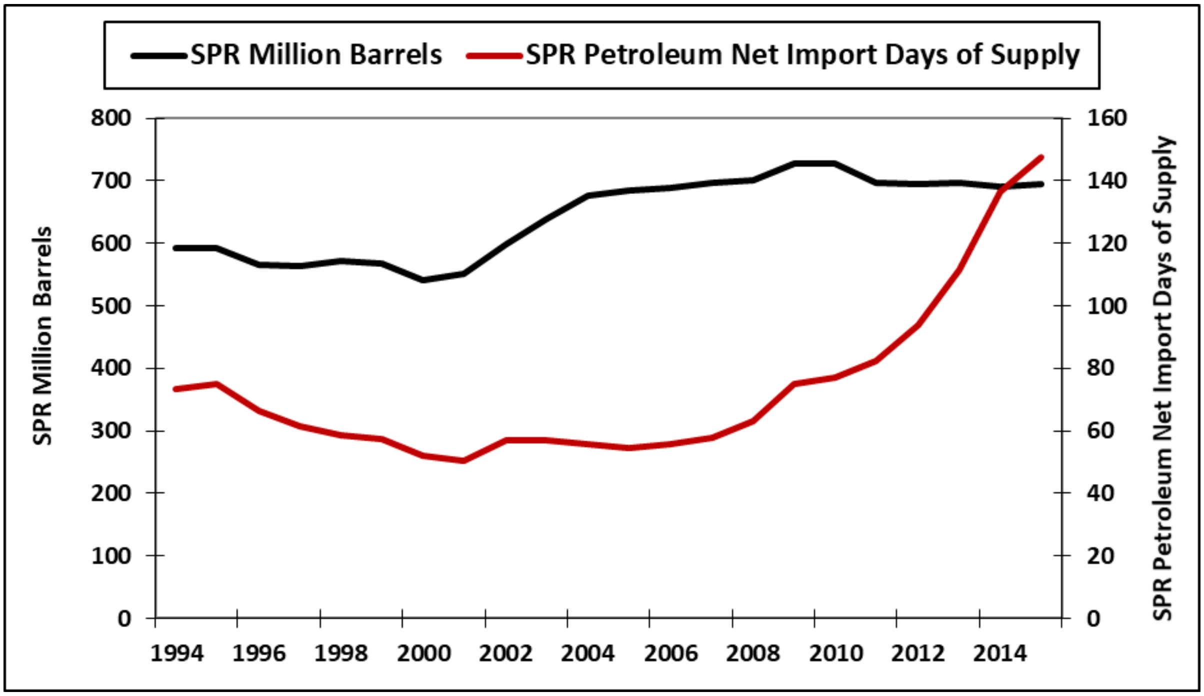
Figure 3.3-2. 1994–2015 Petroleum Net Imports (barrels) and Net Petroleum Trade Deficit (dollars)



Source: EIA 2018a, U.S. Census 2017

In addition to reducing the overall U.S. trade deficit, declines in U.S. net imports of petroleum also reduce the economic vulnerability of the United States to foreign oil supply disruptions. The Strategic Petroleum Reserve (SPR) was created in the 1970s after the 1973–74 embargo of oil flowing into the United States from many oil exporters caused severe U.S. economic disruptions. The strategic and economic protection provided by the SPR can be measured by the *days of petroleum net import supply* that the SPR could provide in the event of a complete halt to foreign oil supplies. This days of petroleum net import supply measure is determined by both the total amount oil held in the SPR and by the extent to which the United States is dependent on net petroleum imports. Figure 3.3-3 shows that the amount of crude oil held in the SPR increased by 17 percent from 1994 through 2005 but the days of petroleum net import supply in the SPR fell by 29 percent over those years because average daily petroleum net imports increased substantially from 1994 through 2005 (Figure 3.3-2). From 2005 through 2015, Figure 3.3-3 shows that the amount of crude oil held in the SPR was almost unchanged (up 1.5 percent) but the days of petroleum net import supply in the SPR increased by 170 percent during the same period because average daily petroleum net imports declined substantially from 2005 through 2015 (Figure 3.3-2). Ongoing forecast declines in U.S. net imports of petroleum will continue to increase the days of petroleum net import supply associated with any given amount of crude oil held in the SPR.

Figure 3.3-3. 1994–2015 Strategic Petroleum Reserve—Million Barrels vs. Days of Petroleum Net Import Supply



SPR = Strategic Petroleum Reserve

3.4 Environmental Consequences

All of the action alternative would contribute to projected ongoing declines in U.S. energy intensity through 2050, but to a smaller extent than the No Action Alternative. Under the No Action Alternative, the average fuel economy of all light duty vehicles in use would increase by 58 percent from 2020 through 2050. Under Alternative 1 (NHTSA's Preferred Alternative), the average fuel economy of all light duty vehicles in use would increase by 40 percent from 2020 through 2050, as older, less efficient vehicles are replaced by new vehicles that achieve much better fuel economy. Gasoline accounts for almost 99 percent of total gasoline gallon equivalent (GGE) use in 2050 under all of the alternatives, so improvements in fuel economy would reduce net petroleum imports. Energy impacts on stationary energy sectors would be negligible due to the limited use of petroleum in those sectors.

Table 3.4-1 shows the direct and indirect impacts of each alternative on combined fuel consumption for 2020 through 2050, by which time almost the entire light-duty vehicle fleet will be composed of MY 2026 or later vehicles. Light-duty vehicle fuel consumption is shown in GGE, which includes consumption of gasoline, diesel, biofuel, and electricity used to power the light-duty vehicle fleet. Table 3.4-1 shows 2020 to 2050 fuel use resulting from the Proposed Action and alternatives compared to the No Action Alternative.

Table 3.4-1. Fuel Consumption and Increase in Fuel Consumption by Alternative (billion gasoline gallon equivalent total for calendar years 2020–2050)

	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Fuel Consumption									
Cars	1,313	1,429	1,425	1,418	1,411	1,385	1,372	1,353	1,358
Light trucks	1,566	1,655	1,646	1,641	1,625	1,612	1,601	1,581	1,590
All light-duty vehicles	2,878	3,084	3,071	3,059	3,036	2,997	2,973	2,935	2,948
Increase in Fuel Consumption Compared to the No Action Alternative									
Cars	--	116	112	105	99	72	59	40	45
Light trucks	--	90	80	76	59	47	35	16	24
All light-duty vehicles	--	206	192	181	158	119	95	56	69

Total light-duty vehicle fuel consumption from 2020 to 2050 under the No Action Alternative is projected to be 2,878 billion GGE. Light-duty vehicle fuel consumption from 2020 to 2050 under the Proposed Action and alternatives is projected to range from 3,084 billion GGE under Alternative 1 to 2,935 billion GGE under Alternative 7. All of the action alternatives would increase fuel consumption compared to the No Action Alternative, with increases that range from 206 billion GGE under Alternative 1 to 56 billion GGE under Alternative 7.

CHAPTER 4 AIR QUALITY

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 household and grooming 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.[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 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 (VOC). 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 would affect the emissions of certain hazardous air pollutants.

Total emissions from on-road mobile sources (highway vehicles) have declined dramatically since 1970 because of pollution controls on vehicles and regulation of the chemical content of fuels, despite continuing increases in vehicle miles traveled (VMT). From 1970 to 2016, emissions from on-road mobile sources declined 89 percent for CO, 71 percent for NO_X, 59 percent for PM2.5, 40 percent for PM10, 93 percent for SO_2, and 90 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 emitting 17.9 million tons per year of CO (30 percent of total U.S. emissions), 133,000 tons per year (2 percent) of PM2.5, and 287,000 tons per year (1 percent) of PM10 (EPA 2016a). Passenger cars and light trucks contribute 93 percent of U.S. highway emissions of CO, 57 percent of highway emissions of PM2.5, and 55 percent of highway emissions of PM10 (EPA 2014g). Almost all of

[1] *Criteria pollutants* is a term used to 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* refer to substances defined as hazardous by the 1990 CAA amendments. These substances include certain VOCs, compounds in particulate matter (PM), pesticides, herbicides, and radionuclides that present tangible hazards based on scientific studies of human (and other mammal) exposure.

the PM in motor vehicle exhaust is PM2.5 (Gertler et al. 2000, EPA 2014g); therefore, this analysis focuses on PM2.5 rather than PM10. On-road mobile sources also emit 1.8 million tons per year (11 percent of total nationwide emissions) of VOCs and 3.6 million tons per year (34 percent) of NO_X, which are chemical precursors of ozone (EPA 2016a). Passenger cars and light trucks emit 90 percent of U.S. highway emissions of VOCs and 51 percent of NO_X (EPA 2014g). 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) contribute to the formation of PM2.5 in the atmosphere; however, on-road mobile sources account for less than 0.68 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 impacts on human health; secondary standards are intended to protect against adverse impacts 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 impacts on human health and public welfare, NAAQS specify different permissible levels for each pollutant. NAAQS for some pollutants include standards for short- and long-term average levels. Short-term standards are intended to protect against acute health impacts from short-term exposure to higher levels of a pollutant; long-term standards are established to protect against chronic health impacts resulting from long-term exposure to lower levels of a pollutant.

Table 4.1.1-1. National Ambient Air Quality Standards

	Primary Standards		Secondary Standards	
Pollutant	**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 standards	
Nitrogen dioxide (NO_2)	0.053 ppm (100 µg/m^3)	Annual (arithmetic mean)	Same as primary standards	
	0.100 ppm (188 µg/m^3)	1 hour[c]	None	
Particulate matter (PM10)	150 µg/m^3	24 hours[d]	Same as primary standards	
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 standards	
Ozone	0.070 ppm	8 hours[g]	Same as primary standards	
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]

[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 2004b).

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 NO_2 concentrations 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 PM2.5 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] To attain this standard, the 3-year average of the 99th percentile of the daily maximum 1-hour average SO_2 concentrations must not exceed 0.075 ppm.
Source: 40 CFR §50, as presented in EPA 2016m
ppm = parts per million; mg/m^3 = milligrams per cubic meter; µg/m^3 = micrograms per cubic meter; CFR = Code of Federal Regulations; EPA = U.S. Environmental Protection Agency; PM10 = particulate matter with a 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 (parts per million or ppm) or in micrograms of a pollutant per cubic meter of air (micrograms per cubic meter or µg/m^3) present in repeated air samples taken at designated monitoring locations. These ambient concentrations of each criteria pollutant are compared to the permissible levels specified by NAAQS to assess whether the region's air quality could be unhealthful.

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 impacts 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 27,188 tons per year (3 percent of total U.S.

[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).

emissions) of acetaldehyde emissions, 2,409 tons per year (4 percent) of acrolein emissions, 54,034 tons per year (26 percent) of benzene emissions, 8,419 tons per year (18 percent) of 1,3-butadiene emissions, and 37,090 tons per year (3 percent) of formaldehyde emissions (EPA 2014c).[4]

Vehicle-related sources of air pollutants include exhaust emissions, evaporative emissions, resuspension of road dust, and tire and brake wear. Locations close to major roadways generally have elevated concentrations of many air pollutants emitted from motor vehicles. Hundreds of studies published in peer-reviewed journals have concluded that concentrations of CO, nitric oxide, NO_2, benzene, aldehydes, PM, 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.

Air pollution near major roads has been shown to increase the risk of adverse health impacts in populations who live, work, or attend school near major roads.[5] A 2013 study estimated that 19 percent of the U.S. population (more than 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 2014d).

In the past 15 years, many studies have reported that populations who live, work, or go to school near high-traffic roadways experience higher rates of numerous adverse health impacts, compared to populations far away from major roads.[6] Numerous studies have found adverse health impacts 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 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

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

[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. 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.

causal association for new onset asthma as between "sufficient" and "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, nonasthmatic respiratory allergy, and cancer in adults and children. Other literature reviews have published conclusions generally similar to the HEI panel conclusions (Boothe and Shendell 2008, Sun et al. 2014). However, researchers from the U.S. Centers for Disease Control and Prevention 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).

Other possible adverse health impacts resulting from high-traffic exposure are less studied and lack sufficient evidence to draw definitive conclusions. Among these less-studied potential outcomes are neurological impacts (e.g., autism and reduced cognitive function) and reproductive outcomes (e.g., preterm birth and 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, *Health Effects of Criteria Pollutants,* and 4.1.1.2, *Health Effects of Mobile Source Air Toxics*, discuss specific health effects associated with each of the criteria and hazardous air pollutants analyzed in this EIS. Section 5.4, *Environmental Consequences*, addresses the impacts of 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

The following sections describe the health effects of the five criteria pollutants addressed in this analysis. This information is adapted from EPA (2012b). The most recent EPA technical reports and *Federal Register* notices for NAAQS reviews provide more information on the health effects of criteria pollutants (EPA 2013d, 2015f).

Ozone

Ozone is a photochemical oxidant and the major component of smog. Ozone is not emitted directly into the air, but is formed through complex chemical reactions among precursor emissions of VOCs and NO_X in the presence of the ultraviolet component of sunlight. Ground-level ozone causes health problems because it irritates the mucous membranes, damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants. Ozone-related health effects also include respiratory symptoms and related effects, aggravation of asthma, increased hospital and emergency room visits, and increased asthma medication usage. 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 nonaccidental 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 reduced 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 affect 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 affect 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 long-term impacts and the potential for the metabolites[7] of these compounds to affect herbivores or insects.

Particulate Matter

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, as well as 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 of emitted gases. 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 (EPA 2012g).

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[7] Metabolites 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 2012g). 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).

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).

EPA classifies DPM as an MSAT, so it is addressed in Section 4.1.1.2, *Health Effects of Mobile Source Air Toxics, Diesel Particulate Matter*.

Carbon Monoxide

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 impacts at birth, such as decreased birth weight.

Sulfur Dioxide

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.

Nitrogen Dioxide

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 reduce resistance to respiratory

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

[10] Highway motor vehicles overall accounted for 30 percent of national CO emissions in 2016 (EPA 2016a). Passenger cars and light trucks account for approximately 93 percent of the CO emissions from highway motor vehicles (EPA 2014g) while heavy-duty vehicles accounted for the remaining 7 percent.

infections. NO_2 has also been linked to other health outcomes, including all-cause (nonaccidental) 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

The following sections 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 known to have noncancer health effects. These compounds include, but are not limited to, acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde. These five air toxics, plus DPM, are the six priority MSATs analyzed in this EIS. These compounds, plus polycyclic organic matter 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 polycyclic organic matter separately, but this matter can occur as a component of DPM and is discussed in *Diesel Particulate Matter*. Naphthalene also is not analyzed separately in this EIS, but it is a member of the polycyclic organic matter class of compounds discussed in *Diesel Particulate Matter*.

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 "reasonably anticipates" acetaldehyde to be a human carcinogen, and the World Health Organization's International Agency for Research on Cancer (IARC) classifies acetaldehyde as possibly carcinogenic to humans (Group 2B) (IARC 1999).

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

Acrolein

Acrolein is extremely acrid and is irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion, and congestion. The intense irritancy of this carbonyl compound has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure (EPA 2003b). The EPA 2003 IRIS human health risk assessment for acrolein (EPA 2003b) summarizes these data and additional

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

studies regarding acute effects of human exposure to acrolein. Evidence 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 2003b). Lesions to the lungs and upper respiratory tracts of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein (EPA 2003c). Animal studies report acute exposure effects such as bronchial hyper-responsiveness (EPA 2003c). 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 nondiseased 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).

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 impacts, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice (EPA 2000b, 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 nonlymphocytic leukemia and chronic lymphocytic leukemia. IARC and the U.S. Department of Health and Human Services have characterized benzene as a human carcinogen (IARC 1987, NTP 2011).

Several adverse noncancer health effects, including blood disorders such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene (Aksoy 1989, Goldstein 1988). The most sensitive noncancer effect observed in humans, based on current data, is depression of the absolute lymphocyte count in blood (Rothman et al. 1996, EPA 2002d). 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).

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 the U.S. Department of Health and Human Services 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 to 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).

Diesel Particulate Matter

Diesel exhaust consists of a complex mixture 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 (black carbon) particles emitted from diesel engines. EPA has not provided a special status, such as a NAAQS or other health-protective measure, 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 nonroad engines because the nonroad engines are generally 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 2002a), 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, International Agency for Research on Cancer, World Health Organization, California EPA, and U.S. Department of Health and Human Services) had made similar hazard classifications prior to 2002.

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern to EPA. EPA derived a diesel exhaust reference concentration from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects. The reference concentration is 5 $\mu g/m^3$ for diesel exhaust measured as DPM. This reference concentration 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 a reference concentration 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 noncancer 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 μg/m^3. In 2012, EPA revised the annual PM2.5 NAAQS to 12 μg/m^3. There is a large and extensive body of human data showing a wide spectrum of adverse health impacts 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 noncancer 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, within a region, and 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 continue to report increased lung cancer risk with occupational exposure to diesel exhaust from older engines. Of particular note since 2011, three new epidemiology studies have examined lung cancer in occupational populations; for example, in truck drivers, underground nonmetal miners, and other diesel-engine-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 reinforce 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 because 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, 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, which considered the evidence indicative of a "probable human carcinogen."

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 noncancer 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, 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; 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 and public comment in June 2010 (EPA 2010e). The draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The National Research Council released their review report in April 2011 (NRC 2011a). EPA is currently revising the draft assessment in response to this review (EPA 2017g).

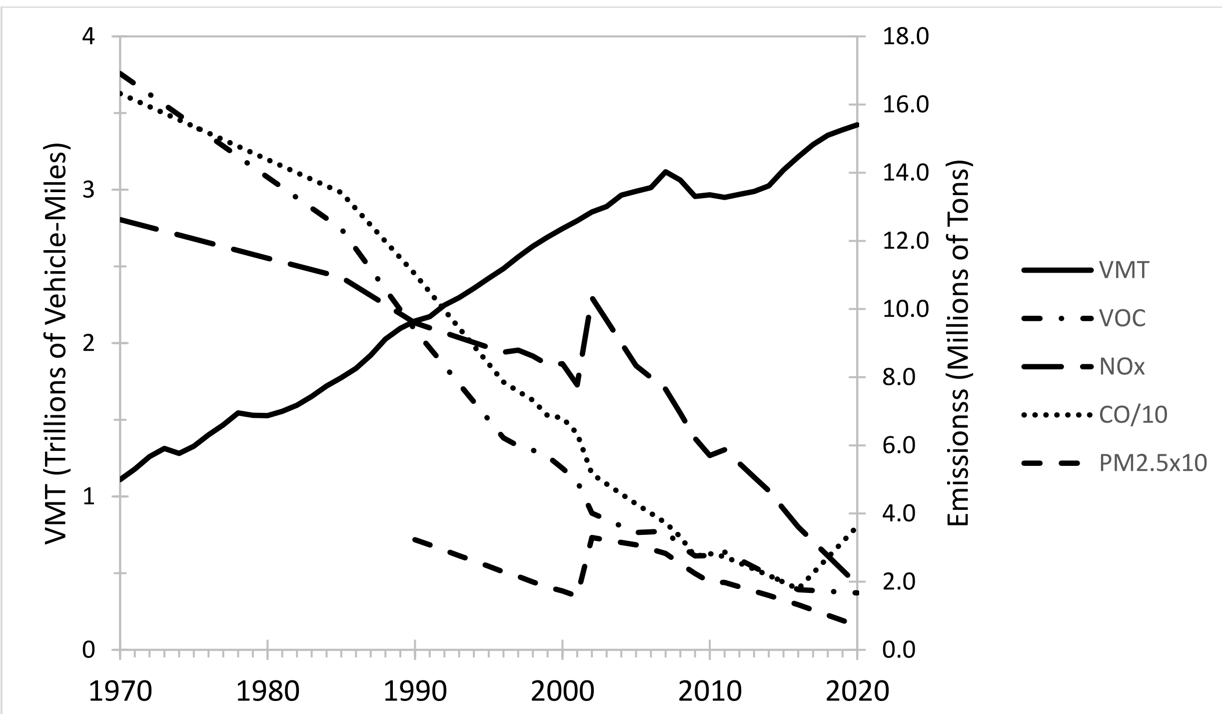
4.1.1.3 Vehicle Emissions Standards

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 heavy-duty vehicles are responsible for the declines in total criteria pollutant emissions from motor vehicles, as discussed in Section 4.1.1, *Relevant Pollutants and Standards*. 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 2000a). 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-MY 2006 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 phases out the Tier 2 vehicle emissions standards and replaces them with Tier 3 standards over MYs 2017–2025. The Tier 3 program will require emission reductions from new passenger cars and light trucks of approximately 80 percent for NO_X and VOCs, and 70 percent for PM. 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 2014b).

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

Figure 4.1.1-1 illustrates current trends in travel and emissions from highway vehicles, not accounting for the impacts of the Proposed Action and alternatives (Section 4.2, *Environmental Consequences*). Since 1970, aggregate emissions traditionally associated with vehicles have decreased substantially even as VMT increased by approximately 173 percent from 1970 to 2014, as shown in Figure 4.1.1-1. For example, NO_X emissions, due mainly to light trucks and heavy-duty vehicles, decreased by 71 percent between 1970 and 2016, despite increases in VMT (EPA 2016a). Future trends show that changes in VMT are having a smaller and smaller impact on emissions because 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.

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



Notes:

[a] Because CO emissions are 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 change in methods made by EPA in 2012 from the MOBILE6.2 model to the MOVES model to calculate emissions for years 2002 and later (EPA 2013f).

Sources: Davis et al. 2016, EPA 2016a, EIA 2017c, IEC 2011

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

4.1.1.4 Conformity Regulations

The CAA prohibits a federal agency from engaging in, supporting, licensing, or approving any activity that does not "conform" to a SIP or Federal Implementation Plan after EPA has approved or promulgated it, or that would affect a state's compliance with the NAAQS.[13] 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[14] applies to transportation plans, programs, and projects that are developed, funded, or approved under 23 U.S.C. or 49 U.S.C. Chapter 53 (Public Transportation). The General Conformity Rule[15] 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.[16] 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 CAFE standards and associated program activities are not developed, funded, or approved under 23 U.S.C. or 49 U.S.C. Chapter 53. Further, the standards are not a highway or transit project funded, approved, or implemented by FHWA or the Federal Transit Administration. Accordingly, this action and associated program activities are not subject to the Transportation 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 Proposed Action would result 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."[17] Because NHTSA's Proposed Action would set fuel economy standards for passenger cars

[13] 42 U.S.C. § 7506(c)(1)-(2).

[14] 40 CFR Part 51, Subpart T, and Part 93, Subpart A.

[15] 40 CFR Part 51, Subpart W, and Part 93, Subpart B.

[16] 40 CFR § 93.153(b).

[17] 40 CFR § 93.152.

and light trucks, it would cause no direct emissions consistent with the meaning of the General Conformity Rule.[18]

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."[19] 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 economy standards would not be caused by NHTSA's action, but rather would occur because of 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."[20]

As the CAFE program uses performance-based standards, NHTSA cannot control the technologies vehicle manufacturers use to improve the fuel economy of passenger cars and light trucks. Furthermore, NHTSA cannot control consumer purchasing (which affects average achieved fleetwide fuel economy) and driving behavior (i.e., operation of motor vehicles, as measured by VMT). It is the combination of fuel economy technologies, consumer purchasing, and driving behavior that results in criteria pollutant or precursor emissions. For purposes of analyzing the environmental impacts of the Proposed Action and alternatives under NEPA, NHTSA has made assumptions regarding all of these factors. This NEPA analysis predicts that increases in air toxic and criteria pollutants would occur in some nonattainment areas under certain alternatives. However, the Proposed Action and alternatives do not mandate specific manufacturer decisions, consumer purchasing, or driver behavior, and NHTSA cannot practically control any of them.[21]

In addition, NHTSA does not have the statutory authority to control the actual VMT by drivers. As the extent of emissions is directly dependent on the operation of motor vehicles, changes in any emissions that result from NHTSA's proposed standards are not changes the agency can practically control or for which the agency has continuing program responsibility. Therefore, the Proposed Action and alternatives would not cause indirect emissions under the General Conformity Rule, and a general conformity determination is not required.

4.1.2 Methods

This section describes the approaches and methods used to estimate the impacts of the Proposed Action and alternatives.

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[18] *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."). NHTSA's action is to establish fuel economy standards for MY 2021–2026 passenger car and light trucks; any emissions increases would occur well after promulgation of the final rule.

[19] 40 CFR § 93.152.

[20] 40 CFR § 93.152.

[21] *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).

4.1.2.1 Overview

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

The air quality analysis accounted for downstream emissions, upstream emissions, the rebound effect, and changes in fleet age resulting from effects of vehicle price changes on vehicle sales[22] (where applicable). In summary, the change in emissions resulting from each alternative would be the sum of the following components:

- Changes in upstream emissions that result from (in this case) increases in fuel consumption and, therefore, higher volumes of fuel production and distribution.
- Decreases in per-vehicle downstream emissions from reductions in VMT rebound and lower overall fleet age. (Newer vehicles have lower emissions per VMT.)
- Increases in per-vehicle downstream emissions from changes in the application of fuel economy technologies.

As discussed in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, the air quality results presented in this chapter, including impacts on human health, are based on 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, including contributions from the power plants that generate the electricity used to recharge electric vehicles and from the production of the fuel burned in those power plants. Emissions and other environmental impacts from electricity production depend on the efficiency of the power plant and the mix of fuel sources used, sometimes referred to as the *grid mix*. In the United States, the current grid mix is composed of coal, natural gas, nuclear, hydroelectric, renewable energy sources, and oil with the largest single source of electricity being from coal (EIA 2017b).

To estimate upstream emissions changes resulting from decreased downstream fuel consumption, the analysis uses emissions factors from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET) model (version 2017 developed by the U.S. Department of Energy, Argonne National Laboratory). Upstream emission factors for gasoline, diesel, E85, and electricity in grams per million British thermal units (MMbtu) were taken from the GREET model in 5-year increments beginning in 1985 and ending in 2040. The agencies developed toxics upstream emission factors that are consistent with EPA's National Emission Inventory and emission factors from the Motor Vehicle

[22] The scrappage model—an econometric survival model that captures the effect of increasing the price of new vehicles on the survival rate of used vehicles—works to quantify impacts on the registered vehicle fleet that exists when a set of new CAFE standards is implemented. It estimates changes in vehicle retirement rates that result from changes in the fuel economy, prices, and other attributes of new cars and light trucks produced during future model years, as well as from other variables that affect owners' decisions about when to retire used vehicles. These other influences include maintenance and repair costs, fuel prices, the fuel economy of vehicles produced during earlier model years, and macroeconomic conditions such as the rates of economic growth and unemployment. Changes in the values of these factors affect the number of used vehicles of different ages that are kept in service rather than being retired, and their continued usage contributes to fuel consumption, emissions, and safety concerns in ways that offset some of the direct effects of changes in CAFE and CO_2 standards.

Emissions Simulator (MOVES) model (EPA 2014d).[23] A spreadsheet model was developed to adjust upstream emission factors to account for the imported share of petroleum.

The analysis presented throughout this EIS assumes that the future electric vehicle fleet would charge from a grid whose mix is uniform across the country. As with gasoline, diesel, and E85, emission factors for electricity were calculated in 5-year increments from 1985 to 2050 in GREET to account for projected changes in the national grid mix. GREET contains information on the intensities (amount of pollutant emitted per unit of electrical energy generated) that extend to 2040. To project the U.S. average electricity-generating fuel mix, the analysis uses the National Energy Modeling System Annual Energy Outlook (AEO) 2017, an energy-economy modeling system from the U.S. Department of Energy.[24]

4.1.2.2 Regional Analysis

Over the course of the development of recent CAFE EISs (NHTSA 2010, 2012) and the medium- and heavy-duty fuel efficiency standards Phase 1 and 2 EISs (NHTSA 2011, 2016c), NHTSA received comments requesting that the agency consider the regional air quality impacts of these programs. NHTSA has included the following information about regional air quality impacts of the Proposed Action and alternatives in response to such comments and because the agency believes that such an analysis provides valuable information for the decision-maker, state and local authorities, and the public. Performing this analysis does not affect the agency's conclusion that a general conformity determination is not required. While a truly local analysis (i.e., at the individual roadway level) is impractical for a 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 impacts 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 air quality problems have been the greatest in these areas. NHTSA assessed only areas that are in nonattainment or maintenance for ozone or PM2.5 because these are the criteria pollutant emissions from passenger cars and light trucks that are of greatest concern to human health. 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 passenger cars and light trucks is PM2.5.[25] Appendix A, *Air Quality Nonattainment Area Results*, provides emissions estimates for all nonattainment and maintenance areas for all criteria pollutants (except lead, as explained in Section 4.1.1.1, *Health Effects of Criteria Pollutants*, under *Lead*). On-road motor vehicles are a minor contributor to SO_2 emissions (less than 0.68 percent of national emissions, as noted above) (EPA 2016a) and are unlikely to affect the attainment status of SO_2 nonattainment and maintenance areas.

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[23] EPA's MOVES model, described in Section 2.4.1.1, *Downstream Emissions*, estimates emissions based on a variety of inputs, including vehicle type and age, fuel type and quality, operating conditions, and vehicle characteristics.

[24] The Annual Energy Outlook (AEO) is the annual energy consumption forecast produced by the U.S. Energy Information Administration (EIA).

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

NHTSA's emissions analysis is national and regional but does not attempt to address the specific geographic locations of changes in emissions within nonattainment and maintenance areas. For example, there is limited evidence that EV use is disproportionately greater in areas with the worst traffic congestion (Section 8.3.3.3, *Other Past, Present, and Reasonably Foreseeable Future Actions*). Because hybrid electric vehicles and plug-in hybrid electric vehicles have lower tailpipe emissions compared to conventionally fueled vehicles, and battery electric vehicles have no tailpipe emissions, greater electric vehicle use in these areas could suggest that tailpipe emissions in urban nonattainment areas would be less than the analysis estimates. However, because of the complication and uncertainties associated with these local variations, NHTSA's emissions analysis does not assume any variation by vehicle type or fuel in the geographic distribution of VMT.

Emissions changes due to the rebound effect would occur from passenger cars and light trucks operating on entire regional roadway networks; any emissions changes due to the 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 change in emissions would be small compared to total emissions from all sources surrounding that location (including existing emissions from traffic already using the road), so the localized impacts of the Proposed Action and alternatives on ambient concentrations and health impacts 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 Analysis Periods

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 pollutant comply with the NAAQS is 1 year.[26] This air quality analysis considers emissions that would occur over annual periods, consistent with the NAAQS. To evaluate impacts on air quality, specific years must be selected for which emissions are estimated and impacts on air quality are calculated.

NHTSA selected calendar years that are meaningful for the timing of likely effects of the alternatives, as follows:

- **2025:** An early forecast year; by 2025 about one-fourth of passenger car and light truck VMT would be accounted for by vehicles that meet fuel economy standards as set forth under the Proposed Action.
- **2035:** A midterm forecast year; by 2035 about three-fourths of passenger car and light truck VMT would be accounted for by vehicles that meet fuel economy standards as set forth under the Proposed Action.
- **2050:** By 2050, almost all passenger cars and light trucks in operation would meet fuel economy standards as set forth under the Proposed Action, and changes in year-over-year impacts would be determined primarily by VMT growth rather than by MY 2021–2026 passenger cars and light trucks replacing older, less fuel-efficient passenger cars and light trucks.

[26] 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; compliance with the annual PM2.5 NAAQS is based on the 3-year average of the weighted annual mean concentrations.

4.1.2.4 Incomplete or Unavailable Information

Where information in this analysis is incomplete or unavailable, NHTSA relies on Council on Environmental Quality regulations regarding incomplete or unavailable information.[27] As noted throughout this methods 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 in the passenger car and light truck fleet, VMT projections, emissions from fuel refining and distribution, and economic factors.

To support the information in this EIS, NHTSA used the best available models and supporting data. The models used for the EIS were subjected to scientific review and were approved by the agencies that sponsored their development. Nonetheless, 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 impacts in the form of cases per ton of criteria pollutant emissions reduced. 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[28]

For each alternative, the CAFE 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 passenger cars and light truck VMT data for all counties in the United States, consistent with EPA's National Emissions Inventory (NEI).[29] 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 CAFE 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

[27] 40 CFR § 1502.22(b).

[28] In Section 4.1.2.5, *Allocation of Exhaust Emissions to Nonattainment Areas,* and Section 4.1.2.6, *Allocation of Upstream Emissions to Nonattainment Areas*, the term *nonattainment* refers to both nonattainment areas and maintenance areas.

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

nonattainment area. Over time, some counties will grow faster than others will, and VMT growth rates will 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 2035 and 2050 compared with analysis year 2025.

The geographic definitions of nonattainment and maintenance areas that NHTSA uses in this document came from the current *Green Book Nonattainment Areas for Criteria Pollutants* (EPA 2017i). 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 2015 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 countywide VMT in the partial county area reflects the proportion of total county population residing in that same area. This technique for allocating VMT to partial counties involves some additional uncertainty because actual VMT per capita can vary according to the characteristics of land use and urban development. For example, VMT per capita can be lower than average in urban centers with mass transit, and higher than average in suburban and rural areas where people tend to drive more (Cook et al. 2006).

The method for allocation of emissions to nonattainment areas is the same for all geographic areas and pollutants. Table 4.1.2-1 lists the current nonattainment and maintenance areas for ozone and PM2.5 and their status and general conformity threshold. Areas for ozone and PM2.5 are listed nonattainment areas for these pollutants encompass the largest human populations. For the complete list of nonattainment and maintenance areas for all pollutants and standards, see Appendix A, *Air Quality Nonattainment Area Results*.

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	Maintenance	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

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
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	KY: Marginal OH, IN: Maintenance	100
Cleveland, OH	PM2.5	Moderate	100
Cleveland-Akron-Lorain, OH	Ozone	Maintenance	100
Cleveland-Akron-Lorain, OH	PM2.5	Maintenance	100
Columbus, OH	Ozone	Maintenance	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	Moderate	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
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

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
Memphis, TN-MS-AR	CO	TN: Maintenance	100
Memphis, TN-MS-AR	Ozone	TN, MS, AR: 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
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

Nonattainment/Maintenance Area	Pollutant	Status[a]	General Conformity Threshold[b]
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 as defined in 40 CFR 1303. Classifications in order of increasing ozone concentration are Marginal, Moderate, Serious, Severe-15, Severe-17, and Extreme. 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 Proposed Action.
Source: EPA 2017i
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 are generated when fuels used by motor vehicles 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.[30] 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 decision-maker and the public, consistent with previous CAFE EISs (NHTSA 2010, 2012) and the heavy-duty fuel efficiency standards EISs (NHTSA 2011, 2016c). NHTSA made a number of important assumptions for this analysis because of 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 method:

- **Feedstock recovery**. NHTSA assumed that little to no extraction of crude oil occurs in nonattainment areas. Of the 50 highest-producing oil fields in the United States, only 10 are in nonattainment areas. These 10 fields accounted for 15 percent of domestic production or 3 percent of total crude-oil imports plus domestic production in 2009 (EIA 2009, 2014a, 2014b). Therefore, because relatively

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

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 50 highest-producing natural gas fields in the United States, eight are in nonattainment areas. These eight fields account for 6 percent of total natural gas imports plus domestic gross withdrawals in 2009 (EIA 2009, 2014c). 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 occurs 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 2014f) to allocate reductions in nationwide total emissions from fuel refining to individual nonattainment areas. These EPA data were projected for 2023, 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 2014f) 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 would change uniformly nationwide as a result of the alternatives.

4.1.2.7 Health Impacts

This section describes NHTSA’s approach to providing quantitative estimates of adverse health impacts of conventional air pollutants associated with each alternative. In this analysis, NHTSA quantified 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 associated with avoided health outcomes. Table 4.1.2-2 lists the health outcomes NHTSA quantified. This method 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 outcomes are calculated for each primary pollutant (NO_X, directly emitted PM2.5, and SO_2) and expressed as adverse health outcomes increased per ton of reduced emissions. Each primary pollutant has a specific factor related to its quantifiable health impacts (expressed as incidence of impacts per ton of emissions). The general approach to calculating the health outcomes associated with each alternative is to multiply these factors by the estimated annual increase in emissions of that pollutant and to sum the results of these calculations for all pollutants. This calculation provides the total health impacts that would result under each alternative.

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

Impacts Quantified	Impacts Excluded from Quantification[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 emergency room visits, nonbronchitis chronic diseases, other ages and populations)
Emergency room visits for asthma	Cardiovascular effects other than those listed
Nonfatal 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 2013e. 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 of emissions increases, NHTSA estimated only the PM2.5-related human health impacts expected to result from increased 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 are formed by chemical reactions in the atmosphere (secondary PM2.5). Increases in NO_X and VOC emissions would also increase ozone formation and the health effects associated with ozone exposure, but there are no incidence-per-ton estimates for NO_X and VOCs because of the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. This analysis does not include any increases in health impacts resulting from greater population exposure to other criteria air pollutants and air toxics because there are not enough data available to quantify these impacts.

Quantified Health Impacts

The incidence-per-ton factors represent the total human health benefits due to a suite of PM-related health impacts for each ton of emissions reduced. The factors are specific to an individual pollutant and source. The PM2.5 incidence-per-ton estimates apply to directly emitted PM2.5 or its precursors (NO_X

and SO_2). NHTSA followed the incidence-per-ton technique used in EPA's PM2.5 NAAQS Regulatory Impact Analysis (RIA) (EPA 2013d), Ozone NAAQS RIA (EPA 2010a), Portland Cement National Emission Standards for Hazardous Air Pollutants RIA (EPA 2010b), NO_2 NAAQS RIA (EPA 2010c), and most recently updated in *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors* (EPA 2013e). 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 incidence derived from two major cohort studies of PM2.5; and baseline incidence rates for hospital admissions, emergency department visits, and asthma prevalence rates. Revised health endpoints, sensitivity analyses, and new morbidity studies 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[31] as reported in the epidemiology literature.[32]

EPA developed national per-ton estimates for selected pollutants emitted through stationary and mobile activity (EPA 2013e). Because the per-ton values vary slightly between the two categories, the total 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 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 benefit 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 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 2013e). 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 method 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). The benefits-per-ton estimates used in this analysis are based on the mortality health outcome factors given in Table 4.1.2-2. The benefit-per-ton estimates are subject to several assumptions and uncertainties, as follows:

- The benefit-per-ton estimates 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.

[31] 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).

[32] The complete method for creating the benefit-per-ton estimates used in this analysis are provided in *Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors* (EPA 2013e and Fann et al. (2009). Note that since the publication of Fann et al. (2009), EPA no longer assumes that there is a threshold in PM-related models of health impacts

- The benefit-per-ton 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 Proposed 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 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. At this time, NHTSA intends to conduct a photochemical modeling analysis for the Final EIS using the same methods as in the CAFE Final EISs (NHTSA 2010, 2012) and the HD Fuel Efficiency Standards Phases 1 and 2 Final EISs (NHTSA 2011, 2016c).
- 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.
- The following uncertainties, among others, are associated with the health impact functions: within-study variability (the precision with which a given study estimates the relationship between air quality changes and health impacts), 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 impact 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 underestimate or overestimate benefits.
- NHTSA was unable to quantify several health-benefits categories because of limitations associated with using benefit-per-ton estimates, several of which could be substantial. Because NO_X and VOCs are also precursors to ozone, reductions in NO_X and VOC emissions would also reduce ozone formation and the health effects associated with ozone exposure. Unfortunately, there are no benefit-per-ton estimates because of the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. The PM-related benefit-per-ton estimates also do not include any human welfare or ecological benefits because of limitations on the availability of data to quantify these impacts 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 2013d) provides more information about the overall uncertainty in the estimates of the benefits of reducing PM2.5 emissions.

Table 4.1.2-3 lists the incidence-per-ton estimates for select PM-related health impacts—mortality and four major morbidity outcomes (derived by the process described above). For the analysis of direct and indirect impacts (Section 4.2, *Environmental Consequences*) NHTSA used these values for the 2025 analysis year (Section 4.1.2.3, *Analysis Periods*). NHTSA applied the values for 2030 to estimate impacts in 2035 and 2050.

Table 4.1.2-3. Incidence-per-Ton Values for Health Outcomes

Year	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)						
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)						
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						
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						
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						
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

Source: EPA 2013e
EPA = U.S. Environmental Protection Agency; NO_X = nitrogen oxides; PM2.5 = particulate matter with a diameter equal to or less than 2.5 microns; SO_2 = sulfur dioxide

The EPA incidence-per-ton estimates shown in Table 4.1.2-3 are national averages and account for effects of upstream and downstream emissions separately. However, they do not reflect localized variations in emissions, population characteristics, or exposure to pollutants. Most upstream emissions are released from elevated points (for example, tall stacks at refineries and power plants) and disperse widely before reaching ground level. The population in a large geographic region could be affected, but pollutant concentrations generally would be relatively low at any one location. On the other hand, concentrations very near an upstream source that releases emissions at a relatively low elevation could be greater. The actual health impacts from human exposure at any particular location would vary with emissions, local meteorology and topography, and population characteristics.

Unlike most upstream emissions, downstream emissions occur across the roadway system and are released at or near ground level. Populations located near roadways could experience relatively greater pollutant levels because the short distance from the roadway allows less pollutant dispersion to occur. Populations located at greater distances from roadways would be larger than the populations near the roadways but would experience much lower pollutant levels. As with upstream emissions, the actual health effects from human exposure at any particular location would vary with emissions, local meteorology and topography, and population characteristics. Because of these variations, the actual change in health impacts per ton of emissions change could be larger or smaller at any particular location than the values in Table 4.1.2-3.

4.2 Environmental Consequences

This section examines the direct and indirect impacts on air quality associated with the Proposed Action and alternatives. NHTSA is proposing Alternative 1 as the Preferred Alternative. The analysis shows that the action alternatives would result in different levels of emissions from passenger cars and light trucks when measured against projected trends under the No Action Alternative. These reductions and increases in emissions would vary by pollutant, calendar year, and action alternative. The more stringent action alternatives generally would result in larger emissions reductions or smaller emissions increases, compared to the No Action Alternative. Chapter 8, *Cumulative Impacts*, examines cumulative air quality impacts.

4.2.1 Criteria Pollutants

4.2.1.1 Emission Levels

Table 4.2.1-1 summarizes the total upstream and downstream[33] national emissions by alternative for each of the criteria pollutants and analysis years. Figure 4.2.1-1 illustrates this information for 2035, the forecast year by which a large proportion of passenger car and light truck VMT would be accounted for by vehicles that meet standards as set forth under the Proposed Action.

Figure 4.2.1-2 shows the changes over time in total national emissions of criteria pollutants under Alternative 1 (the least stringent and highest fuel use action alternative) and Alternative 7 (the lowest fuel use action alternative) to show the highest and lowest ends of the range of emissions impacts over time across action alternatives. Figure 4.2.1-2 shows a consistent time trend among the criteria pollutants. Emissions decline from 2025 to 2050 because of increasingly stringent EPA regulation of emissions from vehicles (Section 4.1.1, *Relevant Pollutants and Standards*) and from reductions in upstream emissions from fuel production, despite a growth in total VMT from 2025 to 2050 (Table 4.2.1-1 and Figure 4.2.1-2). (Note that continued growth in VMT is projected to occur under all alternatives.)

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

Year	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Carbon monoxide (CO)									
2025	8,608,087	8,447,959	8,459,016	8,466,838	8,482,342	8,516,102	8,521,510	8,541,360	8,548,960
2035	6,064,920	5,766,225	5,787,510	5,807,921	5,841,150	5,905,404	5,933,227	5,995,821	5,978,167
2050	5,224,297	5,047,712	5,060,644	5,073,428	5,094,793	5,136,531	5,153,157	5,189,131	5,178,344

[33] Due to modeling limitations, downstream emissions do not include evaporative emissions from vehicle fuel systems.

Year	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Nitrogen oxides (NO_X)									
2025	679,752	674,640	675,030	675,341	675,709	676,888	676,932	677,455	677,861
2035	453,039	452,357	452,447	452,611	452,647	453,076	452,663	452,930	453,071
2050	369,256	377,167	376,668	376,226	375,299	373,917	372,611	370,925	371,935
Particulate matter (PM2.5)									
2025	27,838	27,964	27,954	27,951	27,930	27,904	27,903	27,886	27,883
2035	25,814	25,996	25,981	25,977	25,951	25,932	25,885	25,856	25,883
2050	24,216	24,812	24,770	24,736	24,665	24,560	24,463	24,332	24,416
Sulfur oxides (SO_2)									
2025	135,881	139,779	139,497	139,363	138,878	138,065	137,935	137,414	137,232
2035	127,495	136,313	135,674	135,164	134,077	132,321	131,097	129,308	129,890
2050	118,836	129,699	128,941	128,251	126,896	124,641	123,121	120,797	121,816
Volatile organic compounds (VOCs)									
2025	888,994	885,227	885,472	885,820	885,862	886,719	886,791	887,144	887,503
2035	608,539	618,203	617,623	617,225	616,108	614,643	612,883	611,208	612,204
2050	488,092	511,534	510,114	508,729	506,155	501,775	498,570	493,851	496,213

Figure 4.2.1-1. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks for 2035 by Alternative, Direct and Indirect Impacts

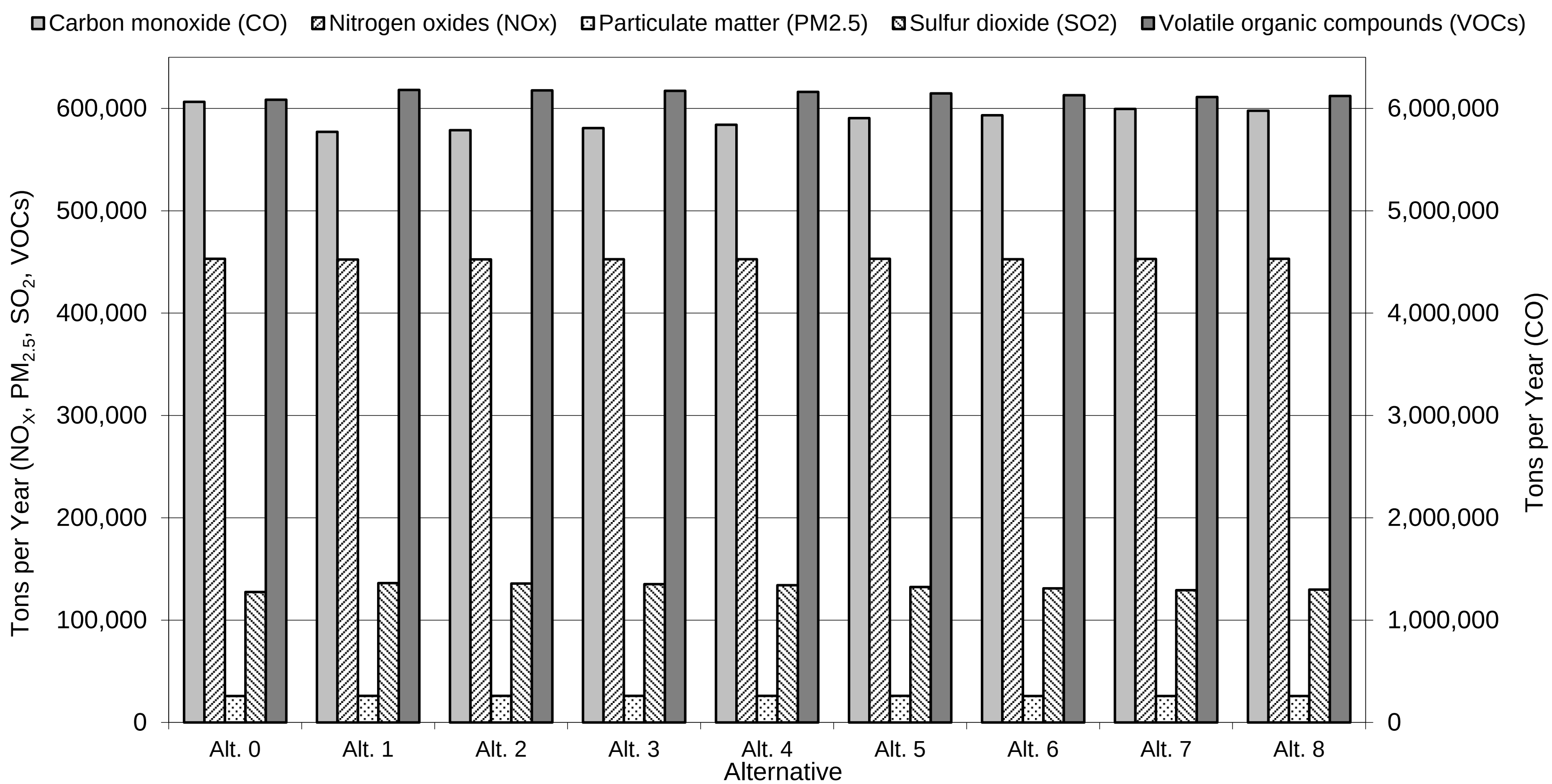
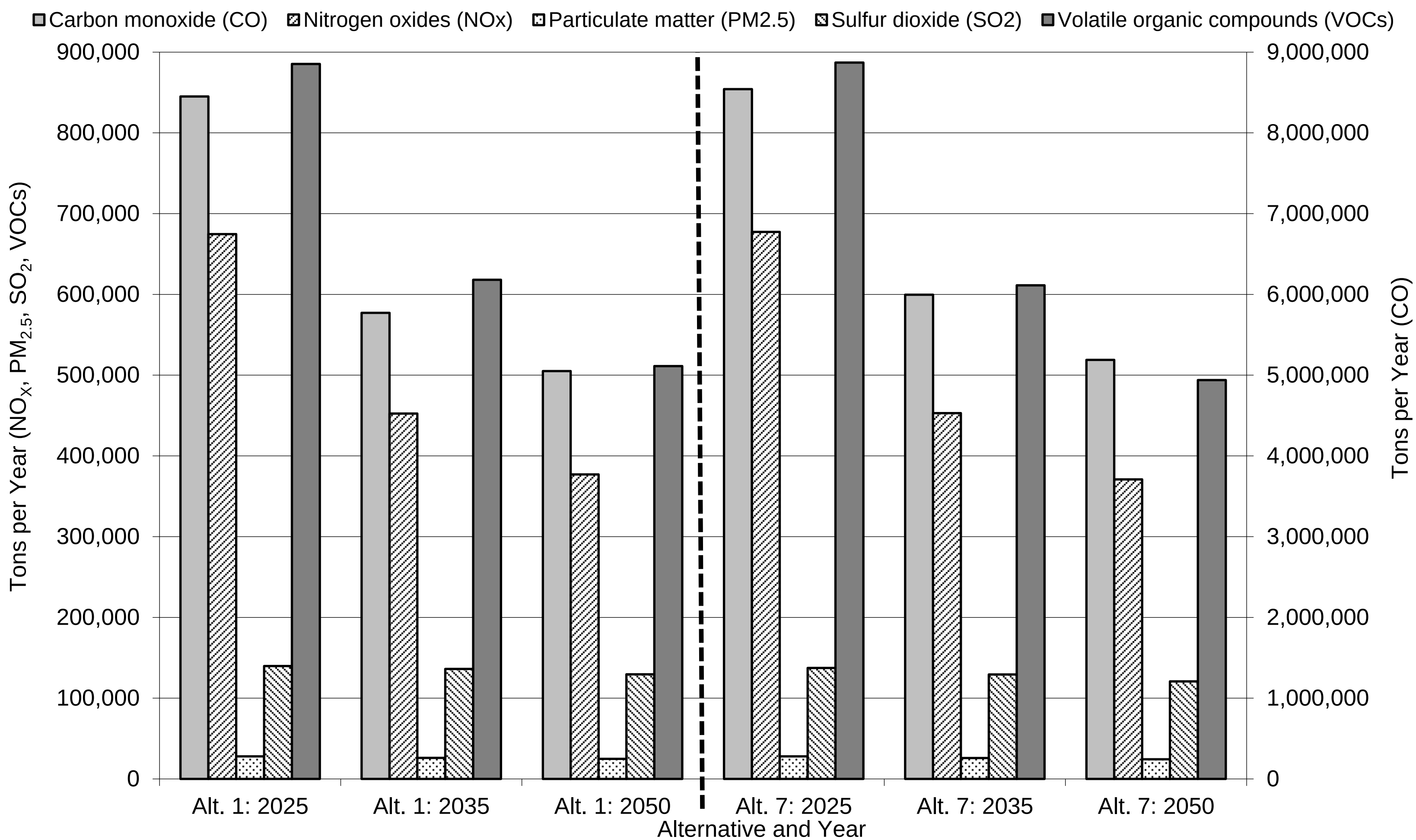


Figure 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks under Alternatives 1 and 7, Direct and Indirect Impacts



Total emissions consist of four components: two sources of emissions (downstream [i.e., tailpipe emissions] and upstream) for each of the two vehicle classes covered by the rule (passenger cars and light trucks). Table 4.2.1-2 shows the total emissions of criteria pollutants by component for calendar year 2035.

Table 4.2.1-2. Nationwide Criteria Pollutant Emissions (tons per year) in 2035 from U.S. Passenger Cars and Light Trucks by Vehicle Type and Alternative, Direct and Indirect Impacts

Vehicle Class	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Carbon monoxide (CO)									
Cars tailpipe	2,911,996	2,792,053	2,797,555	2,804,969	2,811,695	2,826,464	2,843,068	2,872,425	2,859,295
Cars upstream	37,881	41,359	41,230	40,986	40,779	39,891	39,481	38,888	39,039
Trucks tailpipe	3,068,375	2,883,178	2,899,422	2,912,805	2,940,077	2,990,850	3,002,893	3,037,417	3,032,438
Trucks upstream	46,668	49,634	49,303	49,161	48,598	48,199	47,786	47,090	47,395
Total	6,064,920	5,766,225	5,787,510	5,807,921	5,841,150	5,905,404	5,933,227	5,995,821	5,978,167
Nitrogen oxides (NO_X)									
Cars tailpipe	127,206	121,851	122,104	122,440	122,760	123,456	124,177	125,474	124,909
Cars upstream	73,541	80,740	80,487	79,999	79,605	77,854	77,005	75,793	76,115
Trucks tailpipe	160,677	152,205	152,954	153,550	154,775	157,050	157,582	159,142	158,926
Trucks upstream	91,616	97,562	96,903	96,621	95,507	94,715	93,899	92,521	93,120
Total	453,039	452,357	452,447	452,611	452,647	453,076	452,663	452,930	453,071
Particulate matter (PM2.5)									
Cars tailpipe	6,308	5,980	5,995	6,017	6,038	6,088	6,128	6,206	6,176
Cars upstream	5,544	6,046	6,027	5,990	5,961	5,829	5,774	5,687	5,712
Trucks tailpipe	7,090	6,649	6,687	6,720	6,786	6,909	6,938	7,021	7,009
Trucks upstream	6,871	7,321	7,271	7,250	7,166	7,106	7,045	6,941	6,986
Total	25,814	25,996	25,981	25,977	25,951	25,932	25,885	25,856	25,883
Sulfur oxides (SO_2)									
Cars tailpipe	2,763	2,731	2,732	2,733	2,731	2,728	2,737	2,745	2,738
Cars upstream	55,007	60,041	59,855	59,529	59,206	57,952	57,290	56,441	56,605
Trucks tailpipe	3,091	2,909	2,924	2,939	2,969	3,025	3,037	3,071	3,068
Trucks upstream	66,634	70,632	70,163	69,964	69,171	68,616	68,033	67,050	67,480
Total	127,495	136,313	135,674	135,164	134,077	132,321	131,097	129,308	129,890
Volatile organic compounds (VOCs)									
Cars tailpipe	144,942	138,339	138,637	139,050	139,414	140,292	141,130	142,662	142,083
Cars upstream	130,883	144,990	144,536	143,623	142,945	139,755	138,087	135,776	136,422
Trucks tailpipe	167,627	158,763	159,518	160,122	161,341	163,650	164,198	165,797	165,636
Trucks upstream	165,086	176,111	174,932	174,429	172,408	170,947	169,468	166,972	168,064
Total	608,539	618,203	617,623	617,225	616,108	614,643	612,883	611,208	612,204

Table 4.2.1-3 lists the net changes in nationwide criteria pollutant emissions 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 2035. As a general trend, total emissions of each pollutant follow one of two broad patterns of changes with the stringency of the alternatives:

- For CO, NO_X (in 2025 and 2035), and VOC (in 2025), emissions generally decrease across action alternatives compared to the No Action Alternative, with the largest decreases occurring under Alternative 1 and emissions decreases getting smaller from Alternatives 1 through Alternative 8 (the most stringent alternative in terms of required miles per gallon [mpg]). Exceptions to this trend are for CO in 2035 and 2050, which shows the smallest emissions decrease in Alternative 7 and for NO_X in 2035 under Alternative 8, which shows a small increase.
- For NO_X (in 2050), PM2.5, SO_2, and VOC (in 2035 and 2050), emissions generally show increases across action alternatives compared to the No Action Alternative, with the largest increases occurring under Alternative 1, and emissions increases getting smaller from Alternative 1 through Alternative 7. Exceptions to this trend are for PM2.5 and SO_2 in 2025, which show the smallest emissions increase in Alternative 8.

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

Year	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Carbon monoxide (CO)									
2025	0	-160,128	-149,071	-141,249	-125,745	-91,985	-86,577	-66,727	-59,127
2035	0	-298,695	-277,410	-256,998	-223,770	-159,516	-131,692	-69,099	-86,752
2050	0	-176,584	-163,653	-150,869	-129,504	-87,765	-71,140	-35,165	-45,952
Nitrogen oxides (NO_X)									
2025	0	-5,112	-4,722	-4,411	-4,043	-2,865	-2,820	-2,298	-1,891
2035	0	-682	-592	-428	-392	37	-377	-110	32
2050	0	7,911	7,412	6,970	6,043	4,661	3,355	1,669	2,679
Particulate matter (PM2.5)									
2025	0	126	116	114	93	66	66	48	45
2035	0	182	167	163	137	118	71	42	69
2050	0	596	554	520	449	344	247	116	200
Sulfur oxides (SO_2)									
2025	0	3,898	3,616	3,482	2,998	2,184	2,054	1,533	1,351
2035	0	8,819	8,179	7,670	6,582	4,827	3,603	1,813	2,396
2050	0	10,863	10,104	9,414	8,060	5,805	4,285	1,960	2,979
Volatile organic compounds (VOCs)									
2025	0	-3,767	-3,522	-3,175	-3,132	-2,275	-2,203	-1,850	-1,492
2035	0	9,664	9,085	8,686	7,569	6,105	4,344	2,670	3,665
2050	0	23,442	22,022	20,637	18,063	13,682	10,477	5,759	8,121

Notes:
[a] Negative emission changes indicate reductions; positive emission changes are increases.
[b] Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the action alternatives are compared.

For each combination of pollutant and year, the emissions changes generally decrease from Alternative 1 to Alternative 7 compared to the No Action Alternative, reflecting the generally increasing stringency of the alternatives, and then increase from Alternative 7 to Alternative 8, reflecting the differences between these two alternatives as discussed in Section 2.2, *Proposed Action and Alternatives*.

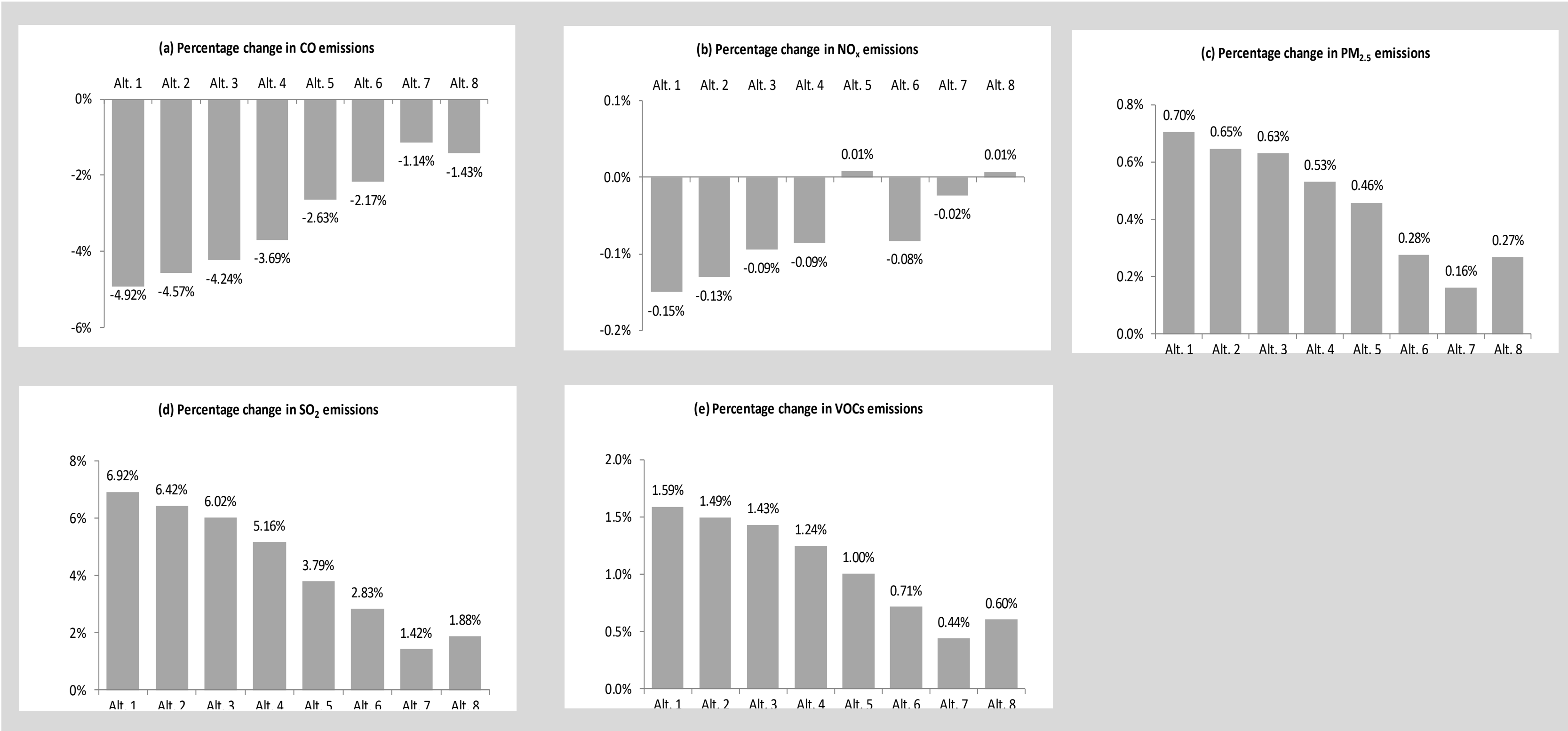
However, the directions and magnitudes of the changes in total emissions are not consistent across all pollutants, which reflects the complex interactions between tailpipe emissions rates of the various vehicle types, the technologies assumed to be incorporated by manufacturers in response to the standards, upstream emissions rates, the relative proportions of gasoline, diesel, and other fuels in total fuel consumption reductions, and increases in VMT. Instances where downstream (tailpipe) emissions are predicted to increase[34] (on a per-VMT basis) in the action alternatives are attributable to shifts in modeled technology adoption from the baseline. Emissions of some criteria air pollutants in some years could increase compared to the No Action Alternative because the reductions in vehicle tailpipe emissions due to the rebound effect (from reduced VMT resulting from decreased vehicle fuel economy) would be offset by upstream emissions increases due to increases in fuel usage. Emissions of some criteria air pollutants in some years could decrease compared to the No Action Alternative where the reductions in vehicle emissions due to the rebound effect would not be offset by upstream emissions increases due to increases in fuel usage.

Under each action alternative compared to the No Action Alternative, the largest relative increases in emissions among the criteria pollutants would occur for SO_2, for which emissions would increase by as much as 9 percent by 2050. The largest relative decreases in emissions would occur for CO, for which emissions would decrease by as much as 5 percent in 2035 (Table 4.2.1-1). Percentage increases and reductions in emissions of NO_X, PM2.5, and VOCs would be less.

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 9 percent because of the interactions of the multiple factors described previously. 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.

[34] Criteria pollutant emissions would not increase above the vehicle emissions but rather would increase within the allowable "headroom" of the standard.

Figure 4.2.1-3. Nationwide Percentage Changes in Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks for 2035 by Action Alternative Compared to the No Action Alternative, Direct and Indirect Impacts



CO = carbon monoxide; NO_X = nitrogen oxides; PM2.5 = particulate matter less than 2.5 microns in diameter; SO_2 = sulfur dioxide; VOC = volatile organic compounds

4.2.1.2 Nonattainment Areas

Table 4.2.1-4 summarizes the criteria air pollutant analysis results by nonattainment area. For each pollutant, Table 4.2.1-4 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur. Appendix A, *Air Quality Nonattainment Area Results*, lists the emissions changes for each nonattainment area. Appendix A indicates that for CO, NO_X, PM2.5, SO_2, and VOCs (in 2025), most nonattainment areas would experience decreases in emissions across all alternatives and years, compared to the No Action Alternative. For VOCs, the numbers of nonattainment areas experiencing decreases and increases would be similar in 2035, and for VOCs in 2050 most nonattainment areas would experience increases in emissions.

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

Criteria Pollutant	Maximum Increase/Decrease	Emission Change (tons/year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Carbon monoxide (CO)	Maximum increase	178	2050	Alt. 1	Baton Rouge, LA [Ozone (2008 8-hour)]
	Maximum decrease	-14,008	2035	Alt. 1	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Nitrogen oxides (NO_X)	Maximum increase	1,220	2050	Alt. 1	Houston-Galveston-Brazoria, TX [Ozone (2008 8-hour)]
	Maximum decrease	-383	2035	Alt. 1	New York, NY-NJ-CT [PM2.5 (2006 24-hour)]
Particulate matter (PM2.5)	Maximum increase	104	2050	Alt. 1	Baton Rouge, LA [Ozone (2008 8-hour)]
	Maximum decrease	-23	2035	Alt. 1	New York, NY-NJ-CT [PM2.5 (2006 24-hour)]
Sulfur dioxide (SO_2)	Maximum increase	786	2050	Alt. 1	Marshall, WV [SO_2 (2010 1-hour)]
	Maximum decrease	-4	2050	Alt. 1	Atlanta, GA [Ozone (2008 8-hour)]
Volatile organic compounds (VOCs)	Maximum increase	2,047	2050	Alt. 1	Denver-Boulder-Greeley-Ft Collins-Loveland, CO [Ozone (2008 8-hour)]
	Maximum decrease	-528	2025	Alt. 1	Los Angeles-South Coast Air Basin Area, CA [NO_2 (1971 Annual)]

Compared to the No Action Alternative, all of the action alternatives could increase or decrease emissions of some criteria air pollutants in some years because of the rebound effect. However, the increases and decreases would not be uniformly distributed to individual nonattainment areas. Most nonattainment areas would experience decreases in emissions of CO, NO_X, PM2.5, SO_2, and VOCs (in 2025). For VOCs in 2035, approximately half of the nonattainment areas would experience increases in emissions while half would experience decreases, while for VOCs in 2050, most nonattainment areas would experience increases in emissions (Appendix A, *Air Quality Nonattainment Area Results*).

4.2.2 Toxic Air Pollutants

4.2.2.1 Emission Levels

Table 4.2.2-1 summarizes the total upstream and downstream[35] emissions of toxic air pollutants by alternative for each of the toxic air pollutants and analysis years. Figure 4.2.2-1 shows toxic air pollutant emissions for each alternative in 2035.

Table 4.2.2-1. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks by Alternative, Direct and Indirect Impacts

Year	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Acetaldehyde									
2025	6,430	6,323	6,331	6,336	6,347	6,369	6,373	6,387	6,392
2035	5,785	5,496	5,516	5,536	5,569	5,632	5,659	5,720	5,703
2050	5,065	4,881	4,894	4,907	4,930	4,973	4,991	5,029	5,017
Acrolein									
2025	356	350	351	351	351	353	353	354	354
2035	302	288	289	290	291	295	296	299	298
2050	273	265	265	266	267	269	270	271	271
Benzene									
2025	20,185	19,800	19,826	19,846	19,880	19,961	19,972	20,019	20,039
2035	12,559	12,093	12,126	12,158	12,207	12,305	12,345	12,444	12,419
2050	9,796	9,614	9,629	9,642	9,663	9,706	9,722	9,760	9,750
1,3-Butadiene									
2025	2,558	2,508	2,512	2,514	2,519	2,529	2,531	2,537	2,539
2035	1,803	1,716	1,722	1,728	1,737	1,755	1,764	1,782	1,777
2050	1,545	1,495	1,498	1,502	1,507	1,518	1,523	1,534	1,530
Diesel particulate matter (DPM)									
2025	27,819	28,708	28,646	28,613	28,509	28,325	28,298	28,181	28,146
2035	26,495	28,633	28,487	28,363	28,122	27,712	27,443	27,025	27,175
2050	24,837	27,449	27,276	27,109	26,805	26,278	25,941	25,399	25,649
Formaldehyde									
2025	4,733	4,662	4,667	4,670	4,677	4,692	4,694	4,703	4,706
2035	3,381	3,269	3,277	3,285	3,297	3,321	3,331	3,355	3,349
2050	2,840	2,798	2,802	2,805	2,810	2,820	2,823	2,832	2,830

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

Figure 4.2.2-1. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks for 2035 by Alternative, Direct and Indirect Impacts

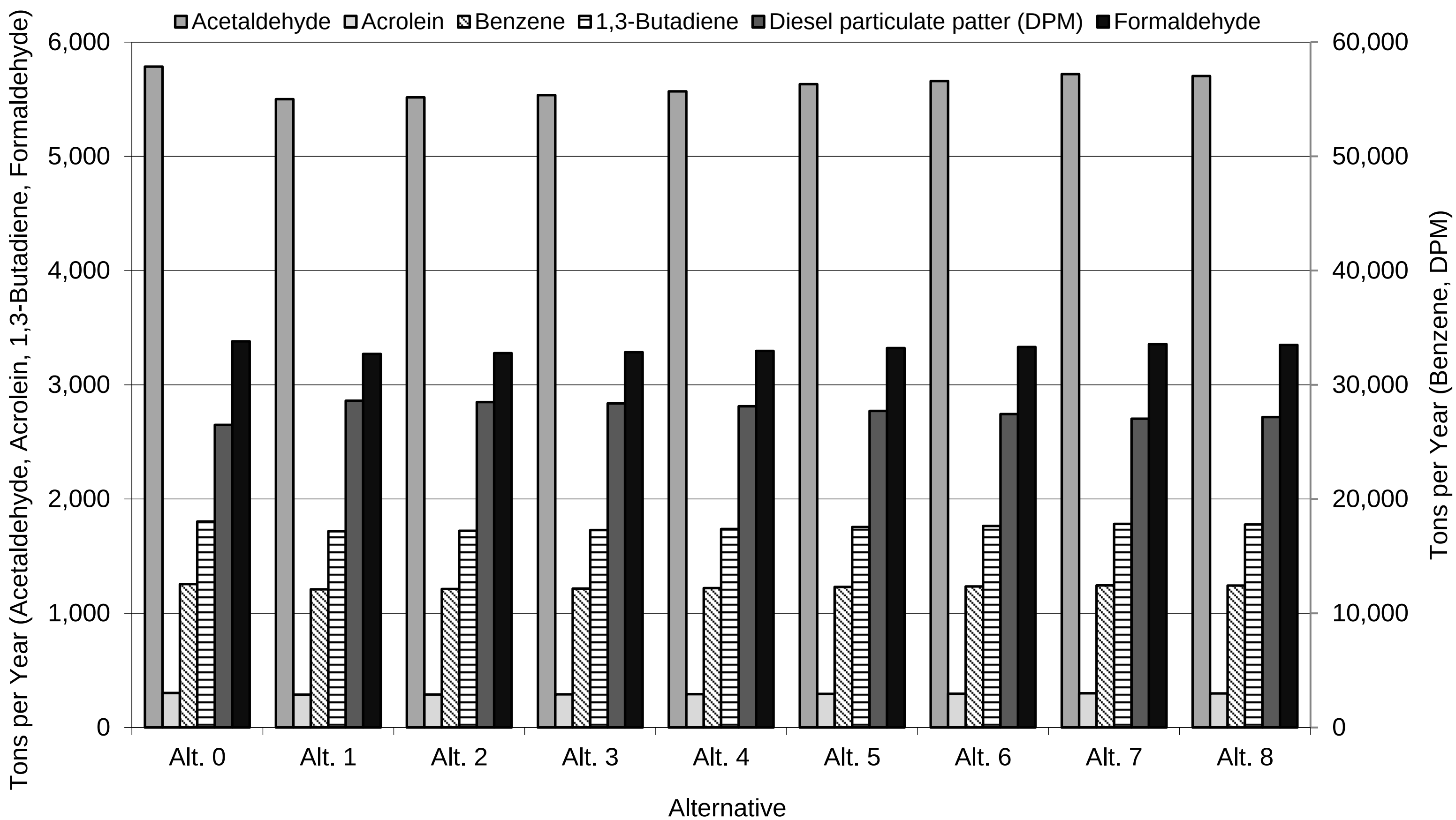


Figure 4.2.2-2 summarizes the changes over time in total national emissions of toxic air pollutants under Alternative 1 (the least stringent and highest fuel-use action alternative) and Alternative 7 (the lowest fuel-use action alternative) to show the highest and lowest ends of the range of emissions impacts. This figure indicates a consistent trend among the toxic air pollutants. Emissions decline from 2025 to 2050 due to increasingly stringent EPA regulations (Section 4.1.1, *Relevant Pollutants and Standards*) and from reductions in upstream emissions from fuel production, despite a growth in total VMT from 2025 to 2050 (Table 4.2.2-2 and Figure 4.2.2-3). (Note that continued growth in VMT is projected to occur under all alternatives.)

As with criteria pollutant emissions, total toxic pollutant emissions consist of four components: two sources of emissions (downstream and upstream) for each of the two vehicle classes (passenger cars and light trucks). Table 4.2.2-2 shows the total emissions of air toxic pollutants by component for calendar year 2035.

Table 4.2.2-3 lists the net change in nationwide emissions for each of the toxic air pollutants and analysis years under the action alternatives compared to the No Action Alternative. Figure 4.2.2-3 shows these changes in percentages for 2035. The trends for toxic air pollutant emissions across the action alternatives generally show decreases (except for DPM) relative to the No Action Alternative for the same reasons as for criteria pollutants. Emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde would generally decrease across the action alternatives (compared to the No Action Alternative) with the largest decreases occurring under Alternative 1, decreases getting smaller from Alternative 1 through Alternative 7, and decreases getting larger from Alternative 7 to Alternative 8. Exceptions to this trend are for acetaldehyde, benzene, 1,3-butadiene, and formaldehyde in 2025, which show the smallest emissions decrease in Alternative 8. Emissions of DPM would be highest under Alternative 1 and would decline across the action alternatives as fuel consumption decreases, with the smallest decreases occurring under Alternative 8 in 2025 and Alternative 7 in 2035 and 2050. These trends are accounted for by the extent of technologies assumed to be deployed under the different action alternatives to meet the different levels of fuel economy requirements. For each combination of pollutant and year, emissions would generally decrease from Alternative 1 to Alternative 7, reflecting the generally increasing stringency of the alternatives, and then would increase from Alternative 7 to Alternative 8, reflecting the differences between these two alternatives as discussed in Section 2.2, *Proposed Action and Alternatives*.

Figure 4.2.2-2. Nationwide Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks under Alternatives 1 and 7, Direct and Indirect Impacts

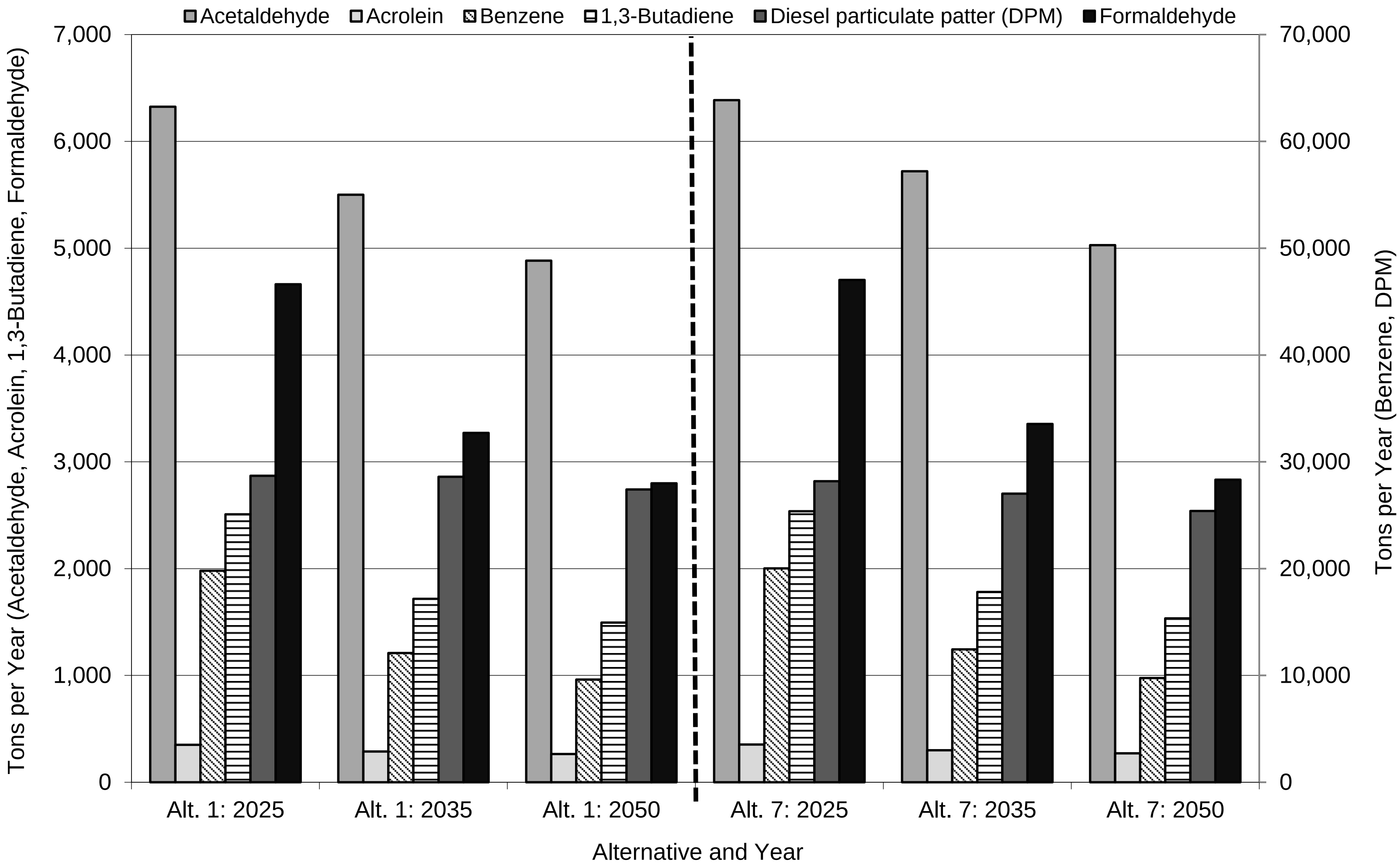


Table 4.2.2-2. Nationwide Toxic Air Pollutant Emissions (tons per year) in 2035 from U.S. Passenger Cars and Light Trucks, by Vehicle Type and Alternative, Direct and Indirect Impacts

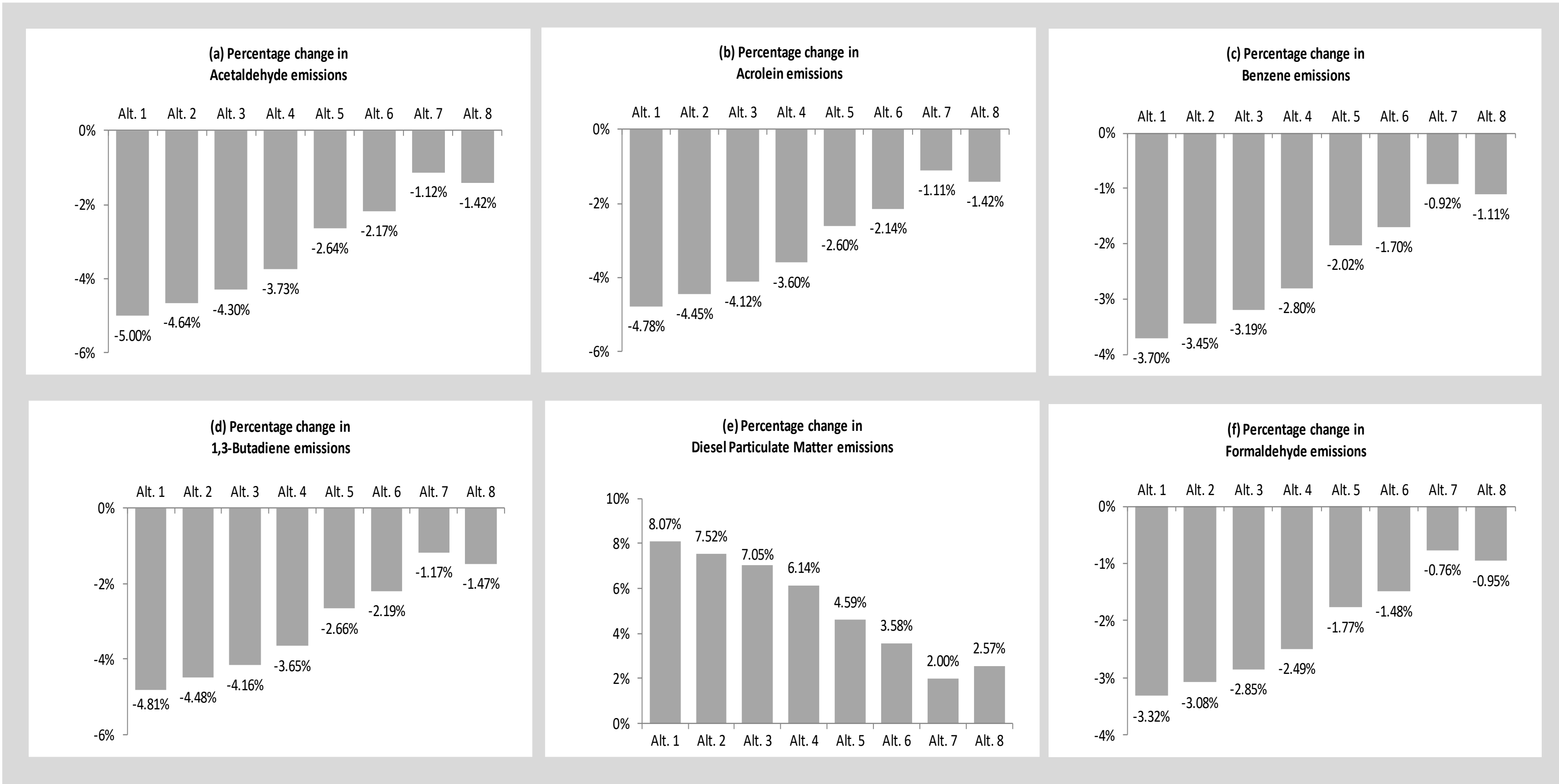
Vehicle Class	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Acetaldehyde									
Cars tailpipe	2,785	2,669	2,675	2,682	2,688	2,703	2,719	2,747	2,734
Cars upstream	25	27	27	27	27	26	26	25	26
Trucks tailpipe	2,944	2,766	2,782	2,795	2,821	2,871	2,883	2,916	2,911
Trucks upstream	31	33	33	33	33	32	32	32	32
Total	5,785	5,496	5,516	5,536	5,569	5,632	5,659	5,720	5,703
Acrolein									
Cars tailpipe	154	147	148	148	148	149	150	152	151
Cars upstream	3	4	4	4	4	4	4	3	4
Trucks tailpipe	141	132	133	134	135	137	138	140	139
Trucks upstream	4	5	5	5	4	4	4	4	4
Total	302	288	289	290	291	295	296	299	298
Benzene									
Cars tailpipe	5,508	5,269	5,280	5,295	5,308	5,338	5,370	5,427	5,403
Cars upstream	498	552	551	547	545	532	526	517	520
Trucks tailpipe	5,922	5,600	5,628	5,651	5,697	5,783	5,803	5,862	5,855
Trucks upstream	630	672	668	666	658	652	647	637	641
Total	12,559	12,093	12,126	12,158	12,207	12,305	12,345	12,444	12,419
1,3-Butadiene									
Cars tailpipe	914	877	878	881	882	887	892	901	897
Cars upstream	5	6	6	6	6	6	6	6	6
Trucks tailpipe	876	826	831	834	842	855	859	868	867
Trucks upstream	7	7	7	7	7	7	7	7	7
Total	1,803	1,716	1,722	1,728	1,737	1,755	1,764	1,782	1,777
Diesel particulate matter (DPM)									
Cars tailpipe	2	2	2	2	2	2	2	2	2
Cars upstream	11,769	12,945	12,905	12,826	12,763	12,481	12,343	12,147	12,200
Trucks tailpipe	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Trucks upstream	14,724	15,685	15,580	15,535	15,356	15,228	15,097	14,876	14,973
Total	26,495	28,633	28,487	28,363	28,122	27,712	27,443	27,025	27,175
Formaldehyde									
Cars tailpipe	1,458	1,396	1,399	1,402	1,406	1,413	1,422	1,437	1,430
Cars upstream	184	204	204	203	202	197	195	191	192
Trucks tailpipe	1,503	1,417	1,425	1,431	1,444	1,467	1,472	1,488	1,486
Trucks upstream	235	251	249	249	246	244	242	238	240
Total	3,381	3,269	3,277	3,285	3,297	3,321	3,331	3,355	3,349

Table 4.2.2-3. Nationwide Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks by Alternative, Direct and Indirect Impacts[a,b]

Year	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Acetaldehyde									
2025	0	-107	-100	-94	-84	-61	-57	-44	-39
2035	0	-289	-269	-249	-216	-153	-126	-65	-82
2050	0	-185	-171	-158	-136	-92	-75	-36	-48
Acrolein									
2025	0	-5	-5	-5	-4	-3	-3	-2	-2
2035	0	-14	-13	-12	-11	-8	-6	-3	-4
2050	0	-8	-8	-7	-6	-4	-4	-2	-2
Benzene									
2025	0	-385	-358	-338	-305	-224	-212	-166	-145
2035	0	-465	-433	-401	-352	-254	-213	-115	-140
2050	0	-182	-168	-154	-133	-90	-75	-36	-46
1,3-Butadiene									
2025	0	-50	-47	-44	-39	-29	-27	-21	-19
2035	0	-87	-81	-75	-66	-48	-39	-21	-26
2050	0	-50	-46	-43	-37	-26	-21	-11	-14
Diesel particulate matter (DPM)									
2025	0	890	827	794	690	506	479	362	328
2035	0	2,138	1,993	1,868	1,627	1,217	948	531	681
2050	0	2,613	2,439	2,273	1,969	1,442	1,105	562	812
Formaldehyde									
2025	0	-71	-66	-63	-56	-41	-39	-30	-26
2035	0	-112	-104	-96	-84	-60	-50	-26	-32
2050	0	-42	-38	-35	-30	-19	-17	-8	-9

Notes:
[a] Negative emission changes indicate reductions; positive emission changes are increases.
[b] Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the action alternatives are compared.

Figure 4.2.2-3. Nationwide Percentage Changes in Toxic Air Pollutant Emissions from U.S. Passenger Cars and Light Trucks for 2035 by Action Alternative Compared to the No Action Alternative, Direct and Indirect Impacts



Under each action alternative compared to the No Action Alternative, increases in emissions among the toxic air pollutants would occur only for DPM, for which emissions would increase by as much as 10 percent by 2050. The largest relative decreases in emissions would occur for acetaldehyde, for which emissions would decrease by as much as 5 percent in 2035 (Table 4.2.2-3). Percentage reductions in emissions of acrolein, benzene, 1,3-butadiene, and formaldehyde would be less.

The differences in national emissions of toxic air pollutants among the action alternatives compared to the No Action Alternative would range from less than 1 percent to 10 percent due to the similar interactions of the multiple factors described for criteria pollutants. 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.

4.2.2.1 Nonattainment Areas

For each pollutant, Table 4.2.2-4 lists the nonattainment areas in which the maximum increases and decreases in emissions would occur.[36] Appendix A, *Air Quality Nonattainment Area Results*, lists the estimated emissions changes for each nonattainment area. Compared to the No Action Alternative, all action alternatives could reduce emissions of most toxic air pollutants but could increase emissions of DPM. Both trends are explained by the rebound effect. However, the increases and decreases in upstream emissions would not be uniformly distributed to individual nonattainment areas. Appendix A, *Air Quality Nonattainment Area Results,* indicates that most nonattainment areas would experience decreases in emissions of acetaldehyde, acrolein, benzene, 1,3-butadiene, and formaldehyde across all action alternatives and years. For DPM, approximately two-fifths of nonattainment areas would experience increases in emissions and three-fifths would experience the same or decreased emissions across all action alternatives and years.

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

Table 4.2.2-4. Maximum Changes in Toxic Air Pollutant Emissions (tons per year) from U.S. Passenger Cars and Light Trucks across All Nonattainment or Maintenance Areas, Alternatives, and Years, Direct and Indirect Impacts

Criteria Pollutant	Maximum Increase/Decrease	Emission Change (tons/year)	Year	Alternative	Nonattainment or Maintenance Area [NAAQS Standard(s)]
Acetaldehyde	Maximum increase	1	2050	Alt. 1	Los Angeles-San Bernardino Counties (West Mojave Desert), CA [Ozone (2008 8-hour)]
	Maximum decrease	-12	2035	Alt. 1	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Acrolein	Maximum increase	1	2050	Alt. 1	AQCR 131: Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties (Minneapolis-St. Paul), MN [SO_2 (1971 24-hour/Annual)]
	Maximum decrease	-1	2035	Alt. 1	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Benzene	Maximum increase	4	2050	Alt. 1	Denver-Boulder-Greeley-Ft Collins-Loveland, CO [Ozone (2008 8-hour)]
	Maximum decrease	-25	2035	Alt. 1	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
1,3-Butadiene	Maximum increase	0.05	2050	Alt. 1	Billings, MT [SO_2 (2010 1-hour)]
	Maximum decrease	-4	2035	Alt. 1	Los Angeles-South Coast Air Basin, CA [Ozone (2008 8-hour)]
Diesel particulate matter (DPM)	Maximum increase	211	2050	Alt. 1	Baton Rouge, LA [Ozone (2008 8-hour)]
	Maximum decrease	-0.01	2025	Alt. 1	Atlanta, GA [Ozone (2008 8-hour)]
Formaldehyde	Maximum increase	6	2050	Alt. 1	Alton Township, IL [SO_2 (2010 1-hour)]
	Maximum decrease	-6	2035	Alt. 1	New York, NY-NJ-CT [PM2.5 (2006 24-hour)]

4.2.3 Health Impacts

Adverse health impacts would increase nationwide under each of the action alternatives compared to the No Action Alternative (Table 4.2.3-1). As discussed in Section 4.1.2.7, *Health Impacts*, the values in Table 4.2.3-1 are nationwide averages. These values account for effects of upstream and downstream emissions separately but do not reflect localized variations in emissions, meteorology and topography, and population characteristics. Although a number of the action alternatives would result in various criteria pollutant and air toxic decreases, emissions of PM2.5, DPM, and SO_2 would increase under all of the action alternatives. As discussed in Section 4.1.2.7, *Health Impacts*, NHTSA's analysis quantifies the health impacts of PM2.5, DPM, and precursor emissions (NO_X and SO_2). However, sufficient data are not available for NHTSA to quantify the health impacts of exposure to other pollutants (EPA 2013e).

As described in Section 4.1.2.7, *Health Impacts*, the changes in premature mortality shown in these tables are measured in several ways. Benefits are measured under the Krewski method and the Lepeule method and at discount rates of 3 and 7 percent. While the number of premature mortalities varies between the two methods, the percent change in mortality when comparing any particular combinations of alternatives and years is equal for the two methods. The adverse health impacts across all outcomes generally would increase from 2025 to 2050. For each combination of pollutant and year, the adverse health impacts would decrease from Alternative 1 to Alternative 7, reflecting the generally increasing stringency of the action alternatives. From Alternative 7 to Alternative 8, adverse health impacts would decrease in 2025 but would increase in 2035 and 2050.

Under any alternative, total emissions from passenger cars and light trucks are expected to decrease over time compared to existing conditions (Table 4.2.1-1). As discussed in Section 4.1.1.3, *Vehicle Emissions Standards*, the phase-in of Tier 3 vehicle emissions standards will decrease the average per-VMT emissions as newer, lower-emitting vehicles replace older, higher-emitting vehicles over time. These decreases are expected to more than offset increases from VMT growth. As a result, under any alternative the total health effects of emissions from passenger cars and light trucks are expected to decrease over time compared to existing conditions.

Table 4.2.3-1. Nationwide Changes in Health Impacts (cases per year) from Criteria Pollutant Emissions from U.S. Passenger Cars and Light Trucks by Alternative, Direct and Indirect Impacts[a,b]

Year	Alt. 0 No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8
Premature mortality (Krewski et al. 2009)									
2025	0	32	29	29	24	18	17	12	11
2035	0	86	80	75	64	48	35	18	24
2050	0	134	124	116	100	73	53	25	39
Premature mortality (Lepeule et al. 2012)									
2025	0	73	68	66	56	41	38	28	25
2035	0	194	179	169	145	109	78	40	55
2050	0	299	278	260	223	163	120	55	87
Acute bronchitis									
2025	0	54	50	49	41	30	28	21	19
2035	0	128	119	112	96	72	52	26	36
2050	0	199	185	173	148	109	79	37	58
Work-loss days									
2025	0	4,480	4,153	4,029	3,405	2,482	2,337	1,713	1,540
2035	0	10,892	10,094	9,521	8,144	6,118	4,398	2,247	3,080
2050	0	16,819	15,650	14,612	12,540	9,196	6,726	3,108	4,881
Emergency room visits: respiratory									
2025	0	15	14	13	11	8	8	6	5
2035	0	39	36	34	29	22	16	8	11
2050	0	62	58	54	47	34	25	12	18

[a] Negative changes indicate fewer health impacts; positive changes indicate additional health impacts.
[b] Changes for the No Action Alternative are shown as zero because the No Action Alternative is the baseline to which the action alternatives are compared.

CHAPTER 5 GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

This section describes how the Proposed Action and alternatives potentially would affect the pace and extent of future changes in global climate. One of the key matters about which federal agencies must use their own judgment is determining how to describe the direct and indirect climate change-related impacts of a proposed action. In this EIS, the discussion compares projected increases in greenhouse gas (GHG) emissions from the Proposed Action and alternatives with GHG emissions from the No Action Alternative. The discussion of consequences of the Proposed Action and alternatives focuses on GHG emissions and their potential impacts on the climate system (atmospheric carbon dioxide [CO_2] concentrations, temperature, sea level, precipitation, and ocean pH). For purposes of this analysis, the standards are assumed to remain in place for model years after 2025 or 2026 (depending on alternative) at the level of the MY 2025 or MY 2026 standards set forth by the agency. This chapter presents results through 2100, the end of the climate change analysis period.

This chapter is organized as follows:

- Section 5.1, *Introduction,* introduces key topics on GHGs and climate change, including uncertainties in assessing climate change impacts.
- Section 5.2, *Affected Environment,* describes the affected environment in terms of current and anticipated trends in GHG emissions and climate.
- Section 5.3, *Analysis Methods*, outlines the methods NHTSA used to evaluate climate effects.
- Section 5.4, *Environmental Consequences*, describes the potential direct and indirect environmental impacts of the Proposed Action and alternatives.

The cumulative impacts of the Proposed Action are discussed in Chapter 8, *Cumulative Impacts*. That chapter includes climate modeling that applies different assumptions about the effect of broader global GHG policies on emissions outside the U.S. passenger car and light truck fleets as well as qualitative discussions of the potential cumulative impacts of climate change on key natural and human resources.

5.1 Introduction

The CEQ NEPA regulations require agencies to ensure the scientific integrity of the information included in an EIS.[1] Given that NHTSA's primary areas of technical and scientific expertise relate to the agency's primary mission to reduce deaths and injuries from motor vehicle crashes, NHTSA has neither developed its own evidence nor drawn its own conclusions relating to climate change. Rather, for its understanding of climate science and analysis of the potential impacts of the alternatives on climate change, NHSTA relies on existing expert panel- and peer-reviewed climate change studies and reports. In particular, this EIS draws primarily on 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 relies on assessment reports because these reports assess numerous individual studies to draw general conclusions about the

[1] 40 CFR § 1502.24.

potential impacts of climate change. Even where assessment reports include consensus conclusions of expert authors, uncertainly still exists, as with all assessments of environmental impacts. See Section 5.1.1, *Uncertainty in the IPCC Framework*, on how uncertainty is communicated in the IPCC reports.

This EIS also draws on peer-reviewed literature that has been published since the release of the IPCC and the GCRP panel-reviewed reports. Because this recent 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 provided 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 decision-makers. This approach is consistent with federal regulations and with NHTSA's approach in its EISs for the MY 2011–2015 CAFE standards, MY 2012–2016 CAFE standards, Phase 1 HD standards, MY 2017–2025 CAFE standards, and the Phase 2 HD standards.

5.1.1 Uncertainty in the IPCC Framework

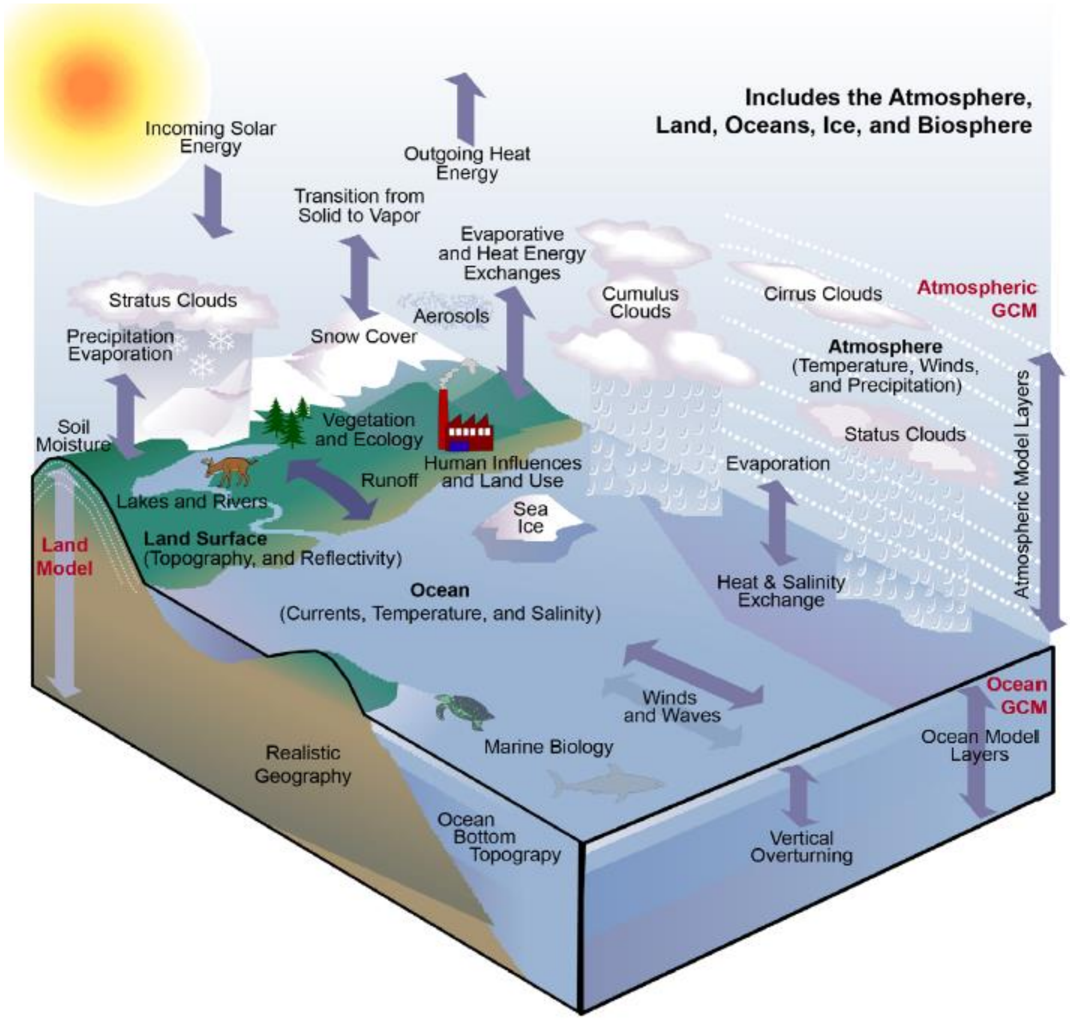
Assessing climate change impacts involves uncertainty. The CEQ regulations require agencies to make clear for potentially significant adverse environmental impacts any incomplete or unavailable information regarding that impact.[2] Similarly, given the global nature of climate change and the need to communicate uncertainty to a variety of decision-makers, 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 are 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 Fifth Assessment Report Summary for Policymakers* (*IPCC WG1 AR5*) (IPCC 2013b) 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 (noted in italics) when discussing qualitative environmental impacts on specific resources. The referenced IPCC documents provide a full understanding of the meaning of those uncertainty terms in the context of the IPCC findings. The *IPCC WG1 AR5* (IPCC 2013a) notes that the two primary uncertainties with climate modeling are model uncertainties and scenario uncertainties.

- **Model uncertainties.** These uncertainties occur when a climate model might not accurately represent complex phenomena in 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 in the climate system.
- **Scenario uncertainties.** These uncertainties arise because of uncertainty in projecting future GHG emissions, concentrations, and forcings (e.g., from solar activity).

[2] 40 CFR § 1502.22.

Figure 5.1.1-1. Some Climate System Processes Included in Climate Models



Source: GCRP 2014
GCM = general circulation model

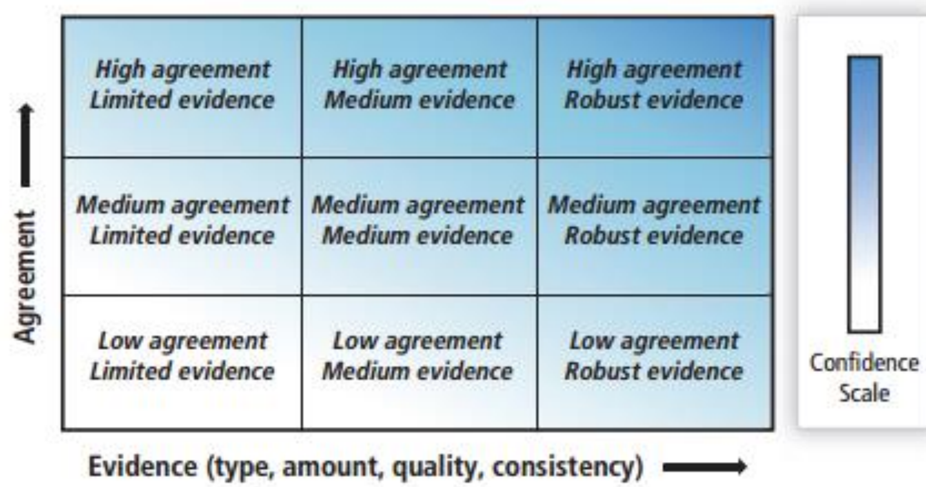
As stated in the *IPCC WG1 AR5*, these types of uncertainties are described by using two metrics for communicating the degree of certainty: confidence in the validity of findings, expressed qualitatively, and quantified measures of uncertainties, expressed probabilistically. The confidence levels synthesize the judgments about the validity of the findings, determined through evaluation of the evidence and the degree of scientific agreement. The qualitative expression of confidence ranges from *very low* to *very high*, with higher confidence levels assigned to findings that are supported by high scientific agreement. The quantitative expression of confidence ranges from *exceptionally unlikely* to *virtually certain*, with higher confidence representing findings supported by robust evidence (Table 5.1.1-1). Figure 5.1.1-2 shows that the degree of confidence increases as evidence becomes more robust and agreement is greater.

Table 5.1.1-1. Standard Terms to Define the Likelihood 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

Notes: Additional terms that were used in limited circumstances in the IPCC Fourth Assessment Report (AR4) (*extremely likely* = 95−100% probability, *more likely than not* ≥ 50−100% probability, and *extremely unlikely* = 0−5% probability) were also used in *IPCC WG1 AR5* when appropriate, and in the *Fourth National Climate Assessment* (GCRP 2017).
Source: IPCC 2013a

Figure 5.1.1-2. Confidence Level as a Combination of Evidence and Agreement



Source: IPCC 2013a

5.1.2 Climate Change and Its Causes

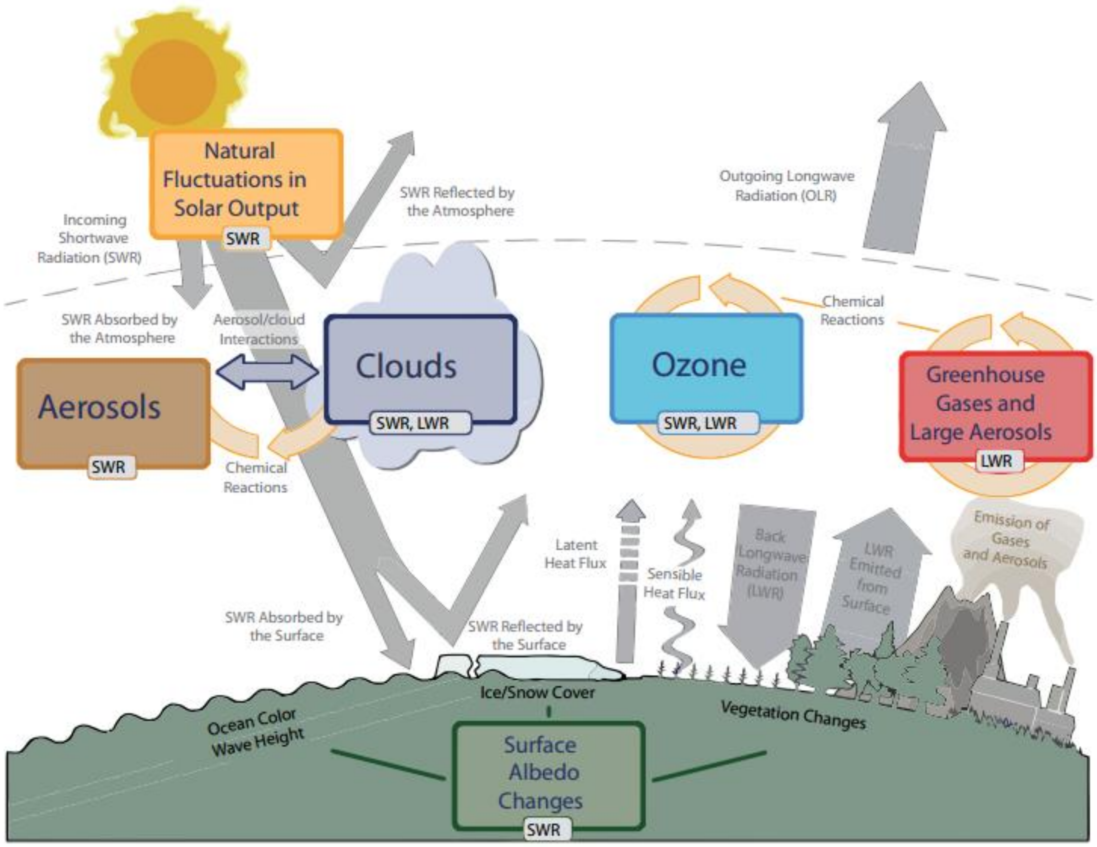
Earth absorbs heat energy from the sun and returns most of this heat to space as terrestrial infrared radiation. GHGs trap heat in the lower atmosphere (the atmosphere extending from Earth's surface to approximately 4 to 12 miles above the surface), absorb heat energy emitted by Earth's surface and lower 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. Human activities, particularly fossil-fuel combustion, lead to the presence of increased concentrations of GHGs in the atmosphere; this buildup of GHGs is changing the Earth's energy balance. IPCC states the warming experienced over the past century is due to the combination of natural climatic forcers (e.g., natural GHGs, solar activity) and human-made climate forcers (IPCC 2013a). IPCC concluded, "[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 *Working Group 1 (WG1) Fourth Assessment Report (AR4)*]. IPCC reports that it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC 2013a).

Although the climate system is complex, scientists have identified the following main drivers of climate change (Figure 5.1.2-1):

- **GHGs**. Primary GHGs in the atmosphere are water vapor, CO_2, nitrous oxide (N_2O), methane (CH_4), and ozone (IPCC 2013a).
- **Aerosols.** Aerosols are natural and human-made particles in the atmosphere that 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 in size) modify the amount of outgoing long-wave radiation (IPCC 2013a). Other particles, such as black carbon, can absorb outgoing terrestrial radiation, causing warming.
- **Clouds**. Depending on cloud height, cloud interactions with terrestrial and solar radiation can vary. Small changes in the properties of clouds can have important implications for both the transfer of radiative energy and weather (IPCC 2013a).
- **Ozone.** Ozone is created through photochemical reactions from natural and human-made gases. In the troposphere, ozone absorbs and reemits long-wave radiation. In the stratosphere, the ozone layer absorbs incoming short-wave radiation (IPCC 2013a).
- **Solar radiation.** 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.[3] 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).

[3] Surfaces on Earth (including land, oceans, and clouds) 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.

Figure 5.1.2-1. Main Drivers of Climate Change



Source: IPCC 2013a; SWR = shortwave radiation; LWR = longwave radiation; OLR = outgoing longwave radiation

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 are highly complex and variable, which complicates the measurement and detection of change. However, an increasing number of studies show that anthropogenic GHG emissions are affecting climate in detectable and quantifiable ways (IPCC 2013b, GCRP 2017).

This section discusses GHG emissions and climate change both globally and in the United States. NHTSA references IPCC and GCRP sources of historical and current data to report trends in GHG emissions and changes in climate change attributes and phenomena.

5.2.1 Greenhouse Gas Emissions and Aerosols —Historical and Current Trends

5.2.1.1 Global Greenhouse Gas 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.

GHGs are gaseous constituents in the atmosphere, both natural and anthropogenic, that absorb and reemit terrestrial infrared radiation. Primary GHGs in the atmosphere are water vapor, CO_2, nitrous oxide (N_2O), methane (CH_4), and ozone. These GHGs occur naturally and because of human activity. Other GHGs, such as the fluorinated gases,[4] are almost entirely anthropogenic in origin and are used in commercial applications such as refrigeration and air conditioning and industrial processes such as aluminum production.

By far the GHG with the largest contribution to warming is CO_2. Global atmospheric CO_2 concentrations have increased 44.6 percent, from approximately 278 parts per million (ppm) in 1750 (IPCC 2013a) to approximately 403 ppm in 2016 (NOAA 2017). In 2014, CO_2 emissions[5] accounted for 76 percent of global GHG emissions on a global warming potential (GWP)-weighted basis,[6] followed by CH_4 (16 percent), N_2O (6 percent), and fluorinated gases (2 percent) (WRI 2018).

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 2014; other major contributors of GHG emissions are agriculture (10 percent) and industrial processes (6 percent) (WRI 2018). Transportation CO_2 emissions—from the combustion of petroleum-based fuels—account for roughly 15 percent of total global GHG emissions, and have increased by 64 percent from 1990 to 2014 (WRI 2018).[7]

In general, global GHG emissions continue to increase, although annual increases vary according to factors such as weather, energy prices, and economics. Comparing observed carbon emissions to projected emissions, the current global trajectory is similar to the most fossil fuel-intensive emissions scenario (A1Fi) in the *IPCC Special Report on Emissions Scenarios* (2000) and the highest emissions scenario (RCP8.5) represented by the more recent Representative Concentration Pathways (RCP)[8] (IPCC 2013a).

5.2.1.2 U.S. Greenhouse Gas Emissions

Most GHG emissions in the United States are from the energy sector, largely CO_2 emissions from the combustion of fossil fuels. Fossil fuel combustion alone accounts for 76 percent of total U.S. emissions (EPA 2018b), with the remaining 24 percent contributed by other energy sources (e.g. energy production), industrial processes and product use, agriculture and forestry, and waste. CO_2 emissions due to combustion of fossil fuels are from fuels consumed in the electric power (36 percent of fossil fuel

[4] Fluorinated GHGs or gases include PFCs, HFCs, SF_6, and NF_3.

[5] These global GHG estimates *do not* include contributions from land-use change and forestry or international bunker fuels.

[6] 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).

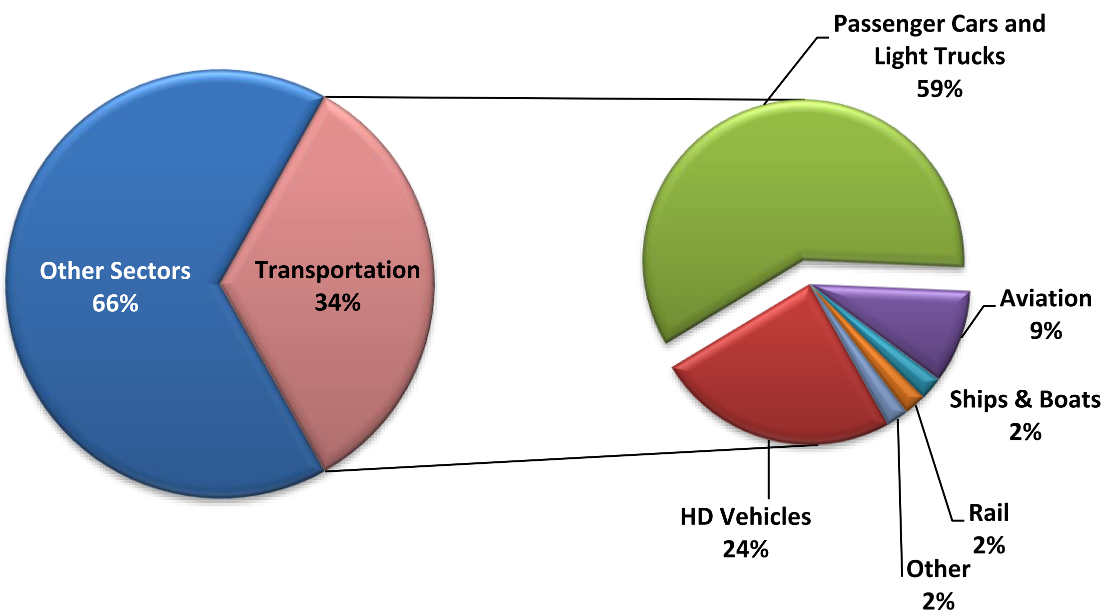
[7] The energy sector is largely composed of emissions from fuels consumed in the electric power, transportation, industrial, commercial, and residential sectors. The 15 percent value for transportation is therefore included in the 72 percent value for energy.

[8] The Representative Concentration Pathways (RCPs) were developed for the IPCC AR5 report. They define specific pathways to emission concentrations and radiative forcing in 2100. The RCPs established four potential emission concentration futures, a business-as-usual pathway (RCP8.5), two stabilization pathways (RCP6.0, 4.5), and an aggressive reduction pathway (RCP2.6).

emissions), transportation (36 percent), industrial (16 percent), residential (6 percent), and commercial (5 percent) sectors (EPA 2018b). In 2016, U.S. GHG emissions were estimated to be 6,586.7 $MMTCO_2e$ (EPA 2018b),[9] or approximately 14 percent of global GHG emissions (WRI 2018).[10]

Similar to the global trend, CO_2 is by far the primary GHG emitted in the United States, representing 81 percent of U.S. GHG emissions in 2016 (EPA 2018b) and accounting for 14 percent of total global CO_2 emissions (WRI 2018).[11] 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 over one-third of total CO_2 emissions from fossil fuels (EPA 2018b).[12] Passenger cars and light trucks account for 59.3 percent of total U.S. CO_2 emissions from transportation (EPA 2018b), an increase of 15.1 percent since 1990 (EPA 2018b). This increase in emissions is attributed to a 43 percent increase in vehicle miles traveled (VMT) because of population growth and expansion, economic growth, and low fuel prices. Additionally, the rising popularity of sport utility vehicles and other light trucks with lower fuel economy than passenger cars has contributed to higher emissions (EPA 2018b, DOT 2016a). Although emissions typically increased over this period, emissions declined from 2008 to 2009 because of decreased economic activity associated with the most recent recession (EPA 2018b). Figure 5.2.1-1 shows the proportion of U.S. CO_2 emissions attributable to the transportation sector and the contribution of each mode of transportation to those emissions.

Figure 5.2.1-1. Contribution of Transportation to U.S. Carbon Dioxide Emissions by Mode (2016)



Source: EPA 2018b
HD = heavy-duty

[9] Most recent year for which an official EPA estimate is available (EPA 2018b).

[10] Based on global and U.S. estimates for 2014, 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.

[11] The estimate for global emissions from the World Resources Institute is for 2012, the most recent year with available data for all GHGs. It excludes emissions and sinks from land use change and forestry.

[12] Apportioning by end use allocates emissions associated with electricity generation to the sectors (residential, commercial, industrial, and transportation) where it is used.

Although CO_2 is the GHG with by far the largest contribution to warming, methane accounts for 10 percent of U.S. GHGs on a GWP-weighted basis, followed by N_2O (5.1 percent) and the fluorinated gases (2.8 percent) (EPA 2018b).

5.2.1.3 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 2013a, 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 2013a, CCSP 2009). Depending on meteorological conditions and other factors, aerosols typically remain in Earth's atmosphere from days to weeks (IPCC 2013a). Their relatively short lifetimes can create regional areas of high aerosol concentrations nearby as well as some distance downwind from emissions source(s) (IPCC 2013a).

An aerosol's impact 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 2013a). In addition, some aerosols attract moisture or water vapor and can affect the lifetime and reflectivity of clouds. Overall, IPCC (2013a) states that there is *high confidence* that aerosols have offset a substantial portion of global mean forcing by cooling Earth's atmosphere from the reflection of incoming sunlight and their interaction with clouds, though large uncertainties exist. 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 2013a).

Among the aerosols, black carbon has recently attracted much attention because of its strong impact 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). There is no single accepted method for summarizing the range of effects of black carbon emissions on the climate or representing these effects and impacts in terms of carbon dioxide equivalent (CO_2e); significant scientific uncertainties remain regarding black carbon's total climate effect. The interaction of black carbon (and other co-emitted aerosols) with clouds is especially poorly quantified (IPCC 2013a), and this factor is key to any attempt to estimate the net climate impacts of black carbon. Although black carbon is likely to be a contributor to climate change, it is not feasible to quantify black carbon climate impacts in an analysis of the Proposed Action and alternatives.

Passenger cars and light trucks (especially those that are diesel-powered passenger cars and diesel-powered light trucks) contribute to U.S. emissions of black carbon, but there is no evidence to suggest that the alternatives would differ substantially in terms of their impact on black carbon and aerosol emissions. For further information on black carbon and aerosol emissions, climatic interactions, and net radiative effect, see Section 5.1.6 of the *Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS* (NHTSA 2016c).

5.2.2 Climate Change Trends

In its most recent assessment of climate change (*IPCC WG1 AR5*), 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). IPCC concludes that, at continental and global scales, numerous long-term changes in climate have been observed. To be more specific, IPCC and the GCRP include the following trends observed over the 20th century as further supporting the evidence of climate-induced changes:

- 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, GCRP 2017).
- Cold-dependent habitats are shifting to higher altitudes and latitudes, and growing seasons are becoming longer IPCC 2014a, GCRP 2017).
- Sea level is rising, caused by thermal expansion of the ocean and melting of snowcaps and ice sheets (IPCC 2013a, GCRP 2017).
- More frequent weather extremes such as droughts, floods, severe storms, and heat waves have been observed (IPCC 2013a, GCRP 2017).
- Oceans are becoming more acidic because of increasing absorption of CO_2 by seawater, which is driven by a higher atmospheric concentration of CO_2 (IPCC 2013a, UN 2016, GCRP 2017). There is *high confidence* that oceans have become increasingly more acidic (IPCC 2013a, UN 2016). A recent assessment found that the oceans have become about 30 percent more acidic over the last 150 years since the Industrial Revolution (GCRP 2017).

World population growth, industrialization, and increases in living standards in developing countries are expected to cause fossil-fuel use and resulting GHG emissions to grow substantially. Global GHG emissions since 2000 have been increasing nearly three times faster than in the 1990s (IPCC 2013a). Based on the current trajectory, IPCC projects that the atmospheric CO_2 concentration could rise to more than three times preindustrial levels by 2100 (IPCC 2013a). 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 2013a).

5.2.2.1 Climate Change Attributes

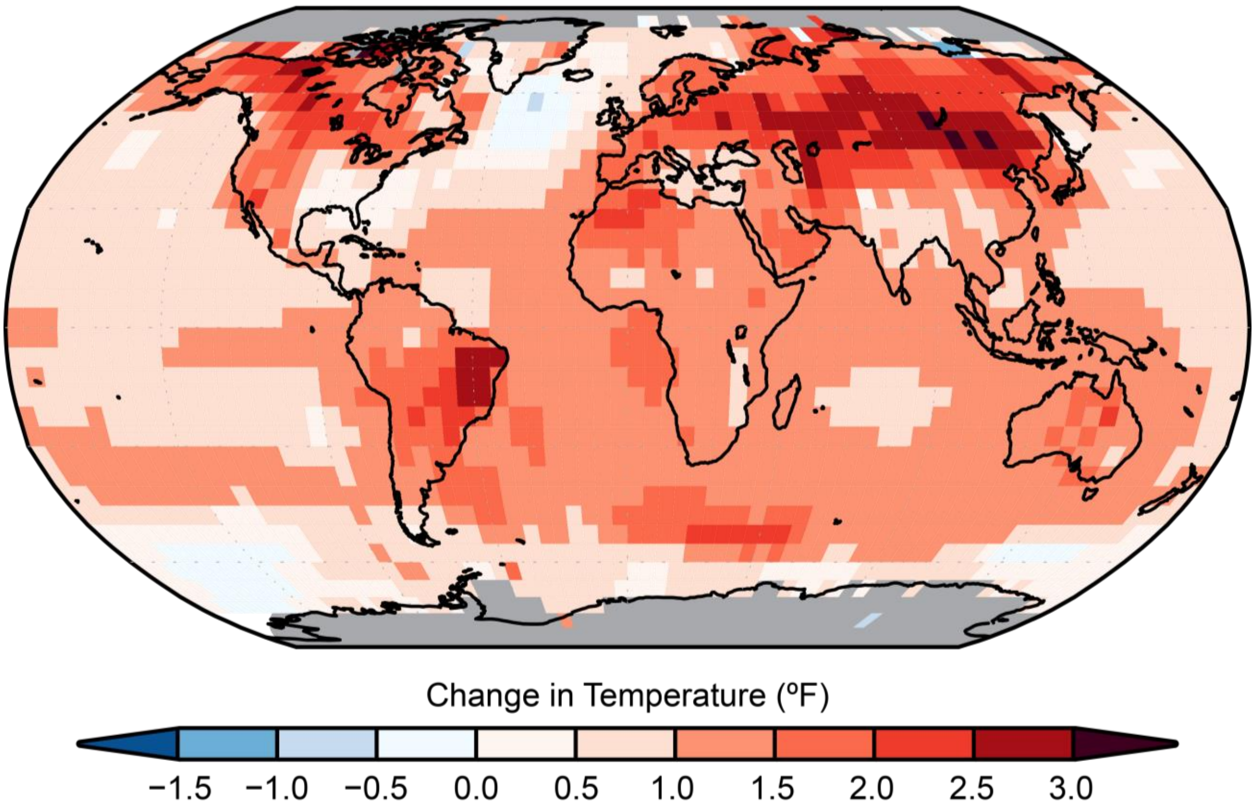
The climate change attributes of temperature, sea-level rise, precipitation, and ocean pH provide evidence of rapid climate change.

Temperature

Global warming is evidenced, in part, by the increase in surface temperatures over time. The last decade has been the warmest on record, and 2016 was the hottest year on record in the continental United States, at 0.94°C (1.69°F) above the 20th century average of 13.9°C (57.0°F).[13] This surpassed the previous global record set in 2015. In 2016, high temperatures were particularly evident in the Arctic (GCRP 2017). Ambient temperatures have increased across most of global lands and oceans in recent decades compared to earlier in the historical record. (Figure 5.2.2-1).

[13] The global temperatures in 2016 were influenced by strong El Niño conditions that prevailed at the beginning of the year.

Figure 5.2.2-1 Global Surface Temperature Anomalies in degrees Fahrenheit from 1986–2015 relative to 1901–1960.



Source: GCRP 2017

The sections that follow discuss radiative forcing, average temperatures, and extreme temperatures as they relate to climate change.

Radiative Forcing

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. Total anthropogenic RF has increased by 2.29 watts per square meter (W/m^2) (plus 1.04 or minus 1.16 W/m^2) and is responsible for the observed warming (IPCC 2013a). The RF from increased atmospheric CO_2 concentration alone is estimated to be 1.68 W/m^2 (plus 0.35 or minus 0.35 W/m^2) (IPCC 2013a). 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).

Average Temperatures

From 1880 to 2016, the global mean surface temperature rose by about 0.9°C (1.6°F) (GCRP 2017). Temperatures are rising at an increasing rate. The average rate of increase since 1951 was 0.12°C (plus or minus 0.03°C) (0.22°F 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 2017). Air temperatures are warming more rapidly over land than over oceans (IPCC 2013a, GCRP 2017). Similar to the global trend, the U.S. average temperature is about 1.8°F warmer than it was in 1895, and this rate of warming is increasing—most of the warming has occurred since 1970 (GCRP 2017).

Surface temperatures are not rising uniformly around the globe. For example, some areas of the southeast region of the United States have experienced "warming holes" because temperature observations during the 20th century suggest minor to no warming trends since 1901 (GCRP 2017).

IPCC predicts a continuing increase in surface temperature between 2081 and 2100, 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 2013a). The oceans have a large heat capacity and have been absorbing more than 90 percent of warming caused by anthropogenic GHG emissions (GCRP 2017). Due to Earth's thermal inertia—whereby it takes a long time for the oceans to absorb heat and dissipate it to the atmosphere—warming could continue for centuries, even if atmospheric CO_2 is stabilized or reduced.

Extreme Temperatures

In many regions, 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, IPCC 2013a, GCRP 2017). Since 1950, the frequency of heat waves 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 in the western states for the last decade is the most severe on record) (GCRP 2017). Additionally, fewer unusually cold days occurred in the past few decades. The number of extreme cold waves peaked in the 1980s and reached a record low in the 2000s, with records dating back to at least 1895 (the inception of detailed recordkeeping) (GCRP 2017). According to IPCC, it is now considered *very likely* that humans have contributed to extreme heat events since the middle of the 20th century and it is *likely* that human activities have doubled the probability of extreme heat events in some regions (IPCC 2013a).

Multiple lines of evidence have recorded increasing temperatures, including weather balloons and more recently satellites (GCRP 2014). In addition, higher temperatures have also been independently confirmed by other global observations. For example, scientists have documented shifts to higher latitudes and elevations of certain flora and fauna habitat (GCRP 2014). 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).

Sea-Level Rise

Global temperature increases affect the climate change attribute of sea-level rise. The sections that follow discuss contributions to sea-level rise, observed global sea-level rise, and observed regional sea-level rise, respectively.

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 accounted for approximately 75 percent of observed sea-level rise. IPCC concludes that it is *very likely* that human contributions to sea-level rise are substantial (IPCC 2013a).

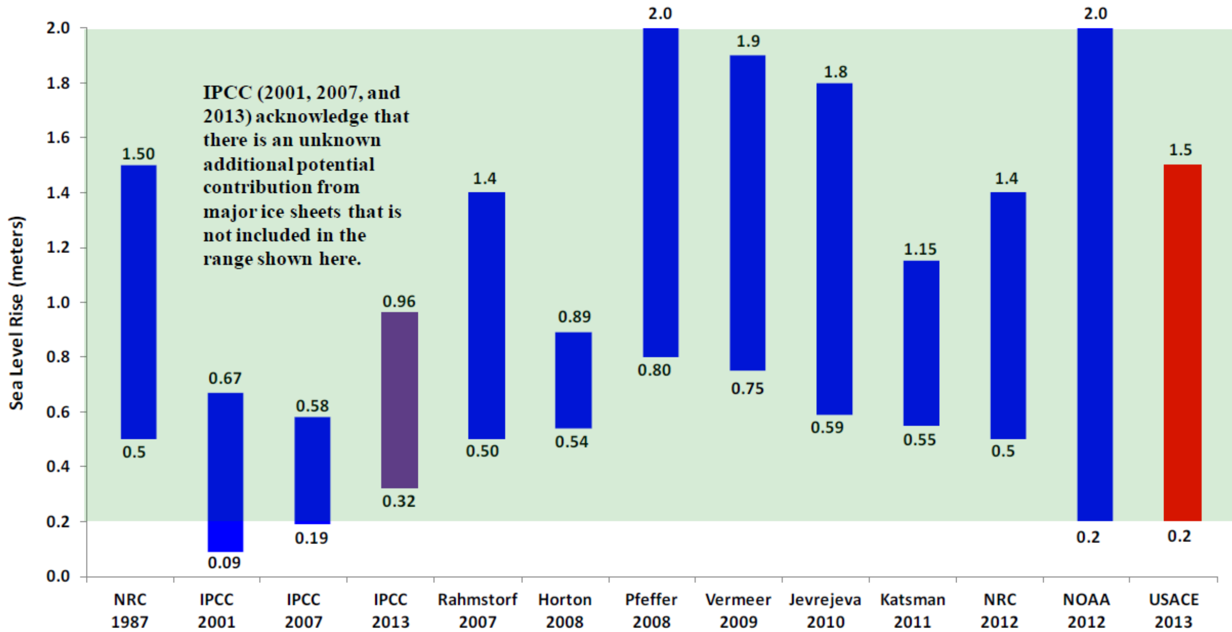
Between 1971 and 2010, global ocean temperature warmed by approximately 0.25°C (0.45°F) in the top 200 meters (0.12 mile) (IPCC 2013a). In the top 700 meters (0.43 mile) of the ocean column, warming contributed an average of 0.6 millimeter (plus or minus 0.2 millimeter) (0.024 inch plus or minus 0.008 inch) per year to sea-level rise (IPCC 2013a). IPCC concludes that 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 subsequent years (IPCC 2013a). 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 2013a).

Observed Global Sea-Level Rise

IPCC states that it is *very likely* that global mean sea level rose at an average rate of 1.7 millimeters (plus or minus 0.3 millimeter) (0.07 inch plus or minus 0.011 inch) per year from 1901 to 2010. The rate increased to approximately 3.2 millimeters (plus or minus 0.4 millimeter) (0.13 inch plus or minus 0.016 inch) per year from 1993 to 2010 (IPCC 2013a). In total, global mean sea level rose about 19 centimeters (7.5 inches) from 1901 to 2010 (IPCC 2013a). IPCC projects that the global temperature increase will continue to affect sea level, causing a *likely* rise of 0.26 meter (0.85 foot) to 0.82 meter (2.7 feet) in the next century (IPCC 2013a).

In addition to IPCC projections, which do not include potential sea-level rise from dynamic calving of major ice sheets, other studies indicate that sea-level rise could be even greater (Figure 5.2.2-2). Most of these studies project a higher sea-level rise than the IPCC studies. In 2017, NOAA found that there is *very high confidence* (more than a 9 in 10 chance) that global mean sea level will rise 0.2 to 2.7 meters (7.9 inches to 8.9 feet) by 2100 (Sweet et al. 2017a). Increasing anthropogenic GHG emissions would increase the risks posed by greater warming and sea-level rise (IPCC 2014a).

Figure 5.2.2-2. End-of-Century Estimates of Maximum and Minimum Global Mean Sea-Level Rise (2090–2100)



Source: USACE 2014

Observed Regional Sea-Level Rise

Sea-level rise is not uniform across the globe, primarily because of 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 2013a citing Beckley et al. 2010).

Nationally, relative sea level has been rising at a rate of 0.8 to 1.2 inches per decade along most of the Atlantic and Gulf coasts and more than 3 inches per decade along portions of the Louisiana coast (where land subsidence is relatively rapid). 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 (39.4 feet) per year (EPA 2009, Nicholls et al. 2007).[14]

Precipitation

As the climate warms, evaporation from land and oceans increases and more moisture can be held in the atmosphere (GCRP 2017). Depending on atmospheric conditions, this evaporation causes some

[14] The shoreline erosion in Louisiana is also affected by human alterations and loss of sediment supply (EPA 2009).

areas to experience 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 2013a). Because of changes in climate, including increased moisture content in the atmosphere, heavy precipitation events have increased in frequency over most land areas (IPCC 2013a).

The sections that follow discuss global, regional, and national trends in precipitation, droughts, streamflow, and snow cover, respectively.

Precipitation

Long-term trends in global precipitation have been observed since 1901. Between 1901 and 2010, increases in precipitation have been observed in the middle 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 Southeast 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 4 percent from 1901 to 2016, on average. The greatest increases from 1991 to 2015 (relative to 1901 to 1960) were noted in the Midwest, the Northeast, and Great Plains, and there were notable decreases in areas of the Southwest (GCRP 2017). Heavy precipitation events also increased, primarily during the last 3 to 5 decades, with more than a 27 percent increase since 1901 in the Northeast (GCRP 2017).

Drought

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 2013a). Spatial variability for dryness is high and data availability is limited in some regions from which to draw global conclusions. IPCC concludes that, 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 2013a).

Drought trends have been changing for some regions of the United States over the past 50 years (GCRP 2017). 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. There are exceptions to this trend, such as the severe drought in the Southwest from 1999 to 2008 (EPA 2009), and severe droughts in Texas and California in 2011 (GCRP 2017), the Midwest in 2012 (GCRP 2017), and California in 2014 and 2015 (USGS 2015). According to tree ring data, drought conditions in the western United States over the last decade could represent the driest conditions in 500 years (GCRP 2017).

Streamflow

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 2013a 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 could have resulted from possible permafrost thawing and increased snowmelt (IPCC 2013a). Changes in precipitation have also been identified as a major driver for changing discharge trends across regions (IPCC 2013a).

Snow Cover

Across the Northern Hemisphere, annual mean snow cover decreased 53 percent from 1967 to 2012 (IPCC 2013a). Changes in air temperature, decreased surface albedo, and increased atmospheric water vapor drove a downward trend in maximum snow cover per decade from 1961 to 2015 across North America (GCRP 2017). The amount of snow at the end of the winter season, which is important for water supply provided by snowmelt, has decreased because of springtime warming (GCRP 2017). In addition, North America, Europe, South Asia, and East Asia have experienced a decreasing number of snowfall events; according to IPCC, this is *likely* due to increasing winter temperatures (IPCC 2013a).

Ocean pH

With higher atmospheric CO_2 concentrations in recent decades, oceans have absorbed more CO_2, which lowers the potential of hydrogen (pH)—or increases the acidity—of the water. When CO_2 dissolves in seawater, the hydrogen ion concentration of the water increases; this is measured as a decrease in pH. Compared to the preindustrial period, the pH of the world's oceans has decreased by 0.1 unit (IPCC 2013a). Because pH is measured on a logarithmic scale, this decrease represents a 30 percent increase in the hydrogen ion concentration of seawater, a substantial acidification of the oceans. Although research on the ultimate impacts of declining ocean pH is limited, available observational, laboratory, and theoretical studies indicate that acidification could interfere with the calcification of coral reefs and inhibit the growth and survival of coral reef ecosystems (EPA 2009, GCRP 2017, IPCC 2013a).

5.2.2.2 Increased Incidence of Severe Weather Events

Heavy precipitation events have increased globally since 1951, with some regional and subregional variability (IPCC 2013a). 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. Identifying long-term trends of tropical cyclones has been difficult because observations were limited prior to the satellite era (IPCC 2013a). 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 2017). The tracks of tropical cyclones have shifted in a warming climate, migrating toward the poles (GCRP 2017).

According to IPCC, 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 2013a). Additionally, recent projections indicate that climate change could increase the frequency of the most intense hurricanes by the end of the century, but it is still unclear how the overall frequency of events might change (GCRP 2017).

Evidence is insufficient to determine whether there are trends in large-scale phenomena such as the Meridional Overturning Circulation (a mechanism for heat transport in the North Atlantic Ocean, by which warm waters are carried north and cold waters are carried toward the equator), or in small-scale phenomena such as tornadoes, hail, lightning, and dust storms (IPCC 2013a).

5.2.2.3 Changes in Ice Cover and Permafrost

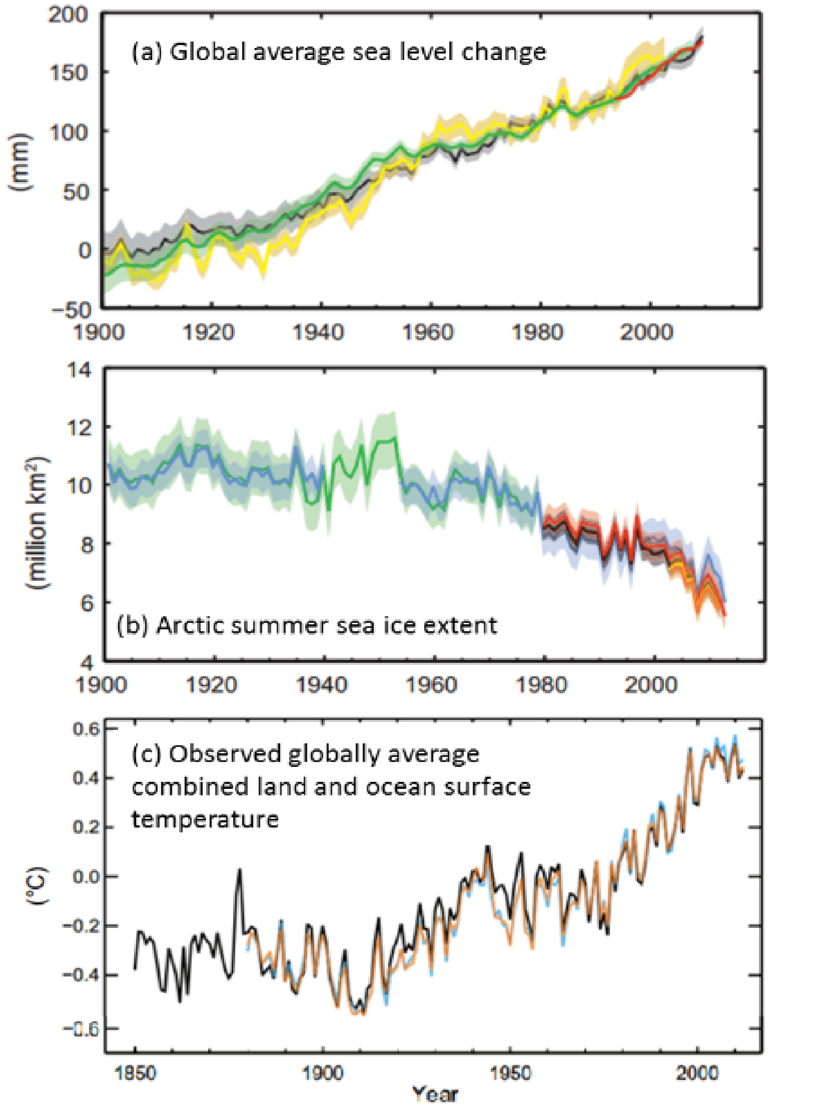
Changes in air and ocean temperatures, precipitation onto the ice mass, and water salinity are affecting glaciers, sea-ice cover, and ice sheets. Numerous studies have confirmed that glaciers and ice sheets have shrunk substantially in the past half century. Satellite images have documented the loss of mass from the Greenland ice sheet and the West Antarctic ice sheet (IPCC 2013a, GCRP 2017). Since 1979, the annual average Arctic sea-ice area has been declining at a rate of 3.5 to 4.1 percent per decade (IPCC 2013a). 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 2013a).[15] Some Arctic ice that previously was thick enough to last through summer has now thinned enough to melt completely in summer. In March 2016, the Arctic experienced the lowest winter maximum ice extent in the satellite record (1979 to 2016), 7 percent below the 1981 to 2010 average (Perovich et al. 2017). Multiyear ice (more than 1 year old) and first-year ice were 22 percent and 78 percent of the ice cover, respectively, compared to 45 percent and 55 percent in 1985 (Perovich et al. 2017). In September 2016, the Arctic sea ice minimum extent was 33 percent lower than the 1981 to 2010 average minimum ice extent, 22 percent larger than the record minimum set in 2012, and tied with 2007 for the second lowest value in the satellite record (1979 to 2016) (Perovich et al. 2017). According to IPCC, 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 2013a). The multiyear ice extent (ice that lasts at least two summers) has declined from about 7.9 million square kilometers (3.05 million square miles) in 1980 to as low as 3.5 million square kilometers (1.35 million square miles) in 2012 (IPCC 2013a). 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).

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 depth of seasonally frozen ground has, in some parts of the Eurasian continent, decreased since 1930 by approximately 0.3 meter (1 foot) (IPCC 2013a). The 4°F 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°F to 8°F (GCRP 2014 citing Hansen and Sato 2012).

Figure 5.2.2-3 shows changes in sea level, Arctic summer sea-ice extent, and surface temperatures.

[15] Permafrost thawing releases CO_2 and CH_4 into the atmosphere.

Figure 5.2.2-3. Changes in Sea Level, Arctic Summer Sea-Ice Extent, and Surface Temperature



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.
Source: IPCC 2013a
mm = millimeters; km^2 = kilometers squared; °C = degrees Celsius

5.3 Analysis Methods

The methods NHTSA used to characterize the effects of the alternatives on climate have three key elements:

- **Analyzing the impacts of each alternative on GHG emissions.** Many analyses of environmental and energy policies and regulations express their environmental impacts, at least in part, in terms of GHG emissions increases or decreases.
- **Estimating the monetized damages associated with GHG emissions increases attributable to each alternative.** Economists have estimated the incremental effect of GHG emissions, and monetized those effects, to express the social costs of carbon, CH_4, and N_2O in terms of dollars per ton of each

gas. By multiplying the emissions increases of each gas by estimates of their social cost, NHTSA derived a monetized estimate of the costs of the emissions increases associated with each action alternative. NHTSA has estimated the monetized damages associated with GHG emissions increases in its Preliminary Regulatory Impact Analysis (PRIA), as indicated by the CO_2 Damage Reduction Benefit metric in the PRIA benefits and net impacts tables. See Chapter 8.11.2 of the PRIA for a description of the methods used for these estimates.

- **Analyzing how GHG emissions increases under each alternative would 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, sea level, and ocean pH.[16] NHTSA translated the changes in GHG emissions associated with each action alternative to changes in temperature, precipitation, sea level, and ocean pH in relation to projections of these climatic parameters under the No Action Alternative.

In this EIS, impacts on GHG emissions and the climate system are expressed in terms of emissions, CO_2 concentrations, temperature, precipitation, sea level, and ocean pH for each of the alternatives.

Comparisons between the No Action Alternative and each action alternative are presented to illustrate the different environmental impacts of each alternatives. The impact of each action alternative is measured by the difference in the climate parameter (CO_2 concentration, temperature, sea level, precipitation, and ocean pH) under the No Action Alternative and the climate parameter under that action alternative. For example, the increase in CO_2 emissions attributable to an action alternative is measured by the difference in emissions under the No Action Alternative and emissions under that alternative.

The methods used to characterize emissions and climate impacts consider multiple sources of uncertainty. Sources of uncertainty include the following sources, in addition to many other factors:

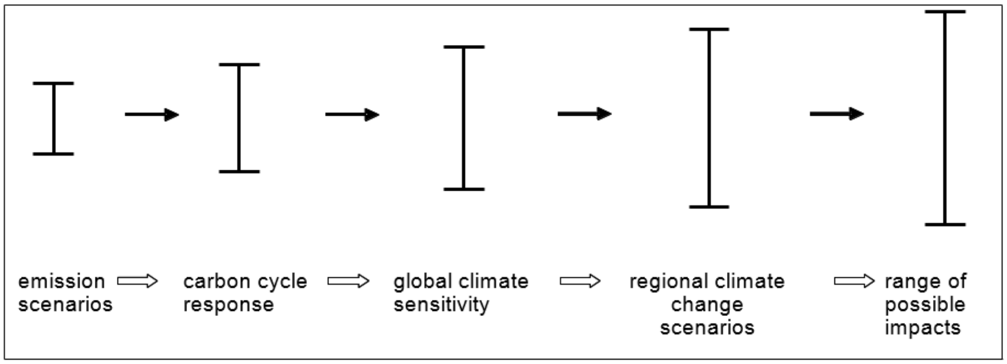
- The pace and effects of technology changes in the transportation sector and other sectors that emit GHGs.
- Changes in the future fuel supply and fuel characteristics that could affect emissions.
- Sensitivity of climate to increased GHG concentrations.
- The rate of change in the climate system in 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.
- Sensitivity to natural variability, such as El Niño conditions.

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 global climate sensitivity, which is even 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 8.6.5, *Health, Societal, and Environmental Impacts of Climate Change*). Although the

[16] In discussing impacts on ocean pH, this EIS uses both *changes to* and *reductions of* ocean pH to describe ocean acidification. The metric pH is a parameter that measures how acidic or basic a solution is. The increase in atmospheric concentration of CO_2 is causing acidification of the oceans, which can be measured by a decrease in ocean pH.

uncertainty bands broaden with each successive step in the analytic chain, not all values within the bands are equally likely; the mid-range values have the highest likelihood.

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 decision-making, 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, 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, including the Model for the Assessment of Greenhouse Gas-Induced Climate Change (MAGICC) and the Object-Oriented Energy, Climate, and Technology Systems (objECTS) version of the Global Change Assessment Model (GCAM), are widely available and are commonly used in the scientific community.

The U.S. Climate Change Science Program Synthesis and Assessment Product 3.1 report 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 Synthesis and Assessment 3.1 report and Chapter 9 of *IPCC WG1 AR5* useful in understanding the issues that underpin the modeling of environmental impacts of the Proposed Action and alternatives on climate change.

5.3.1 Methods for Modeling Greenhouse Gas Emissions

The emissions estimates in this EIS include GHG emissions from passenger car and light truck fuel combustion (tailpipe emissions) as well as upstream emissions from the production and distribution of fuel. GHG emissions were estimated by the DOT Volpe National Transportation Systems Center using the following models: the CAFE Compliance and Effects model (referred to as the CAFE model), described in Section 2.3.1, *CAFE Model*, to calculate tailpipe emissions, and the Greenhouse Gases and Regulated Emissions in Transportation (GREET) model, developed by the U.S. Department of Energy (DOE) Argonne National Laboratory, to estimate emissions associated with production, transportation, and storage of gasoline and diesel from crude oil as well as emissions associated with the generation of electricity. The CAFE model uses emissions factors (amount of pollutant emitted per unit of source activity (e.g., grams per VMT) derived from EPA's Motor Vehicle Emissions Simulator (MOVES).

Emissions under each action alternative were compared against those under the No Action Alternative. GHG emissions were estimated using the methods described in Section 2.3, *Standard-Setting and EIS Methods and Assumptions*. For the climate analysis, GHG emissions trajectories are projected through the year 2100. NHTSA estimated GHG emissions for the passenger car and light truck fleets for 2061 to 2100 by applying the projected rate of change in U.S. transportation fuel consumption over this period from GCAM.[17] For 2061 through 2100, the GCAM Reference and GCAM 6.0 scenarios project that U.S. road transportation fuel consumption will decline slightly because of assumed improvements in efficiency of internal combustion engine-powered vehicles and increased deployment of noninternal 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 2011–2015 CAFE Final EIS,* the *MY 2012–2016 CAFE Final EIS* (NHTSA 2010), *Phase 1 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS* (NHTSA 2011), *MY 2017–2025 CAFE Final EIS* (NHTSA 2012), and the *Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS* (NHTSA 2016c).

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, carbon monoxide (CO), and volatile organic compounds (VOCs).

Higher fuel consumption from less stringent passenger car and light truck CAFE standards would result in higher emissions of CO_2 (the main GHG emitted) because of refining, distribution, and use of transportation fuels.[18] 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. Higher fuel consumption increases 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.

NHTSA estimated increases in CO_2 emissions resulting from fuel consumption increases by assuming that the carbon content of gasoline, diesel, and other fuels is converted entirely to CO_2 during the

[17] 2060 is the last year for which the CAFE model provides estimates of fleet CO_2 emissions for this analysis.

[18] For this rulemaking, NHTSA estimated emissions of vehicular CO_2, CH_4, and N_2O emissions, but did not estimate vehicular emissions of HFCs. HFCs are released to the atmosphere only through air-conditioning system leakage and are not directly related to fuel efficiency. NHTSA's authority under the Energy Policy and Conservation Act, as amended by the Energy Independence and Security Act, extends only to the regulation of vehicle fuel efficiency. For reference, CH_4 and N_2O account for 1.5 percent of the tailpipe GHG emissions from passenger vehicles and light trucks, and CO_2 emissions account for the remaining 98.5 percent. Of the total (including nontailpipe) GHG emissions from passenger cars and light trucks, tailpipe CO_2 represents approximately 94.7 percent, tailpipe CH_4 and N_2O represent approximately 1.5 percent, and HFCs represent approximately 3.9 percent (values are calculated from EPA 2012b).

combustion process.[19] 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).

Increased fuel consumption also increases CO_2 emissions that result from the use of carbon-based energy sources during fuel production and distribution. Volpe estimated the increase in CO_2 emissions during each phase of fuel and electricity production and distribution (upstream emissions) using CO_2 emissions rates obtained from the GREET model using previous assumptions about how fuel increases are reflected in increases in activity during each phase of fuel production and distribution.[20] The total increase in CO_2 emissions under each alternative is the sum of the increases in motor vehicle emissions from increased fuel combustion compared to the No Action Alternative plus the increase in upstream emissions from a higher volume of fuel production and distribution than is projected under the No Action Alternative.

5.3.2 Social Cost of Greenhouse Gas Emissions

One approach to assessing the potential impact associated with changes in GHG emissions is to monetize those impacts. The social cost of each gas (i.e., the social cost of carbon (SC-CO_2), methane (SC-CH_4), and nitrous oxide (SC-N_2O) is a metric that estimates the monetary value of impacts associated with marginal changes in emissions in a given year. It 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.

As described in NHTSA's scoping notice, the comparison of the potential impacts of the Proposed Action and alternatives using the SC-CO_2 (i.e., monetization of the potential climate change impacts) appears in the PRIA. Chapter 8.11.2 of the PRIA describes of the methods used for the calculation of SC-CO_2 estimates, and Chapter 12 of the PRIA presents the results of that SC-CO_2 calculation under each alternative. Because one of the primary purposes of NHTSA's PRIA is to monetize and compare the potential costs and benefits of the Proposed Action and alternatives for the benefit of the decision-maker and the public, the agency believes that is the appropriate place for this analysis. Readers may consult the Notice of Proposed Rulemaking (NPRM) for a description of how the monetized cost-benefit analysis factors into its decision-making process. The NPRM and PRIA are both available for public review and comment.

5.3.3 Methods for Estimating Climate Effects

This EIS estimates and reports the projected changes in GHG emissions, particularly CO_2, that would result from the alternatives. The change in GHG emissions is a direct effect of the reduced stringency in passenger car and light truck fuel economy associated with the action alternatives. The changes in CO_2

[19] This assumption results in a slight overestimate of CO_2 emissions, because a small fraction of the carbon content of gasoline is emitted as CO and unburned hydrocarbons. However, the magnitude of this overestimation is likely to be extremely small. This approach is consistent with the recommendation of IPCC for Tier 1 national GHG emissions inventories (IPCC 2006).

[20] Some modifications were made to the estimation of upstream emissions, consistent with NHTSA and EPA assumptions in the NPRM. Section 10.2.3 of the PRIA provides more information regarding these modifications.

emissions, in turn, cause indirect effects on five attributes of climate change: CO_2 concentrations, temperature, sea level, precipitation, and ocean pH.

The subsections that follow describe methods and models used to characterize the changes in GHG emissions and the indirect effects on the attributes of climate change.

5.3.3.1 MAGICC Modeling

NHTSA used a reduced-complexity climate model (MAGICC) to estimate the changes in CO_2 concentrations and global mean surface temperature, and used increases in global mean surface temperature combined with an approach and coefficients from the *IPCC WG1 AR5* (IPCC 2013a) 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 increases 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 CAFE model 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:

- 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 2013a), 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 (Meinshausen et al. 2011).
- MAGICC is publicly available and was designed for the type of analysis performed in this EIS.
- More complex atmospheric-ocean general circulation models 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 2007).[21]

5.3.3.2 Sea-Level Rise

NHTSA estimated the projected changes in global mean sea level based on data from the *IPCC WG1 AR5* (IPCC 2013a).[22] 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

[21] 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.

[22] Sea-level rise outputs from MAGICC6 were not used, as this component of the model is still under development.

based on the climate ensemble data of the RCP[23] 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 Ocean pH

NHTSA projected changes in ocean pH using the CO_2 System Calculations (CO2SYS) model, which calculates parameters of the CO_2 system in seawater and freshwater. This model translates levels of atmospheric CO_2 into changes in ocean pH. A lower ocean pH indicates higher ocean acidity, while a higher pH indicates lower acidity. The model was developed by Brookhaven National Laboratory and Oak Ridge National Laboratory and is used by both the U.S. Department of Energy and EPA. Orr et al. (2015) compared multiple ocean carbon system models, and found that the CO2SYS model was more efficient at analyzing observed ocean chemistry data than other models.

This model uses two of four measurable parameters of the CO_2 system, total alkalinity, total inorganic CO_2, pH, and either fugacity or partial pressure of CO_2 to calculate the remaining two input parameters. NHTSA used the CO2SYS model to estimate the pH of ocean water in the year 2040, 2060, and 2100 under the No Action Alternative and each of the action alternatives. For each action alternative, total alkalinity and partial pressure of CO_2 were selected as inputs. The total alkalinity input was held constant at 2,345 micromoles per kilogram of seawater and the projected atmospheric CO_2 concentration (ppm) data was obtained from MAGICC model runs using each action alternative. NHTSA then compared the pH values calculated from each action alternative to the No Action Alternative to determine the impact of the Proposed Action and alternatives on ocean pH.

5.3.3.4 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 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.

In 2003, 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* (IPCC 2000) was released. The strategy recognized that it would be important to have a consistent set of

[23] RCP2.6, 4.5, 6.0, and 8.5.

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 five different emissions trajectories from each of three 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.

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 CCSP SAP 2.1.

NHTSA and EPA also used the GCAM Reference scenario for the Regulatory Impact Analyses (RIAs) of the Phase 1 and Phase 2 HD National Program Final Rules, 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.

The impact of each action alternative was simulated by calculating the difference between annual GHG emissions under the No Action Alternative and emissions under that 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 passenger cars and light trucks in the United States in 2040 under the No Action Alternative are estimated to be 1,002 $MMTCO_2$;[24] the emissions in 2040 under Alternative 1 are estimated to be 1,097 $MMTCO_2$. The difference of 95 $MMTCO_2$ represents the increase in emissions projected to result from adopting Alternative 1. Global emissions for the GCAM Reference scenario in

[24] The emissions estimates in this EIS include GHG emissions resulting from passenger car and light truck fuel combustion (tailpipe emissions), as well as upstream emissions from the production and distribution of fuel.

2040 are estimated to be 51,701 MMTCO_2, and are assumed to incorporate emissions from passenger cars and light trucks in the United States under the No Action Alternative. Therefore, global emissions under Alternative 1 are estimated to be 95 MMTCO_2 more than this reference level or approximately 51,796 MMTCO_2 in 2040. 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 CAFE 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.

5.3.3.5 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 increases in emissions estimated to result from each of the action alternatives compared to projected emissions under the No Action Alternative. They assume a climate sensitivity of 3°C (5.4°F) for a doubling of CO_2 concentrations in the atmosphere.[25] The approach uses the following four steps to estimate these changes:

1. NHTSA assumed that global emissions under the No Action Alternative would follow the trajectory provided by the global emissions scenario.
2. NHTSA assumed that global emissions for each action alternative would be equal to the global emissions under the No Action Alternative plus the increase 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 plus the emissions increases from that alternative. All SO_2 increases 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.

5.3.3.6 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 2013a). 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 WG1 AR5* expresses stronger confidence in some fundamental processes in models that determine climate sensitivity than the AR4 (IPCC 2013a). According to IPCC, with a doubling of the

[25] NHTSA used a climate sensitivity of 3°C, as this is the midpoint of IPCC's estimated range. IPCC states, "the equilibrium climate sensitivity (ECS) is likely in the range 1.5°C to 4.5°C" (IPCC 2013b).

concentration of atmospheric CO_2, there is a *likely* probability of an increase in surface warming in the range of 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 2013a).

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 three of the alternatives—the No Action Alternative, Alternative 1, and Alternative 7—because this was deemed sufficient to assess the effect of various climate sensitivities on the results.

The approach uses the following four steps to estimate the sensitivity of the results to alternative estimates of the climate sensitivity:

1. NHTSA used the GCAM Reference scenario to represent emissions from the No Action Alternative.
2. Starting with the respective GCAM scenario, NHTSA assumed that the increases in global emissions of CO_2, CH_4, N_2O, SO_2, NO_X, CO, and VOCs resulting from the least stringent alternative (Alternative 1) would be equal to the global emissions of each pollutant under the No Action Alternative plus emissions of each pollutant under Alternative 1. Separately, NHTSA used the same approach for Alternative 7 (the highest GHG emissions alternative) as compared to the No Action Alternative.[26] All SO_2 increases 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 2013a) 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, *Environmental Consequences*, 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).

5.3.4 Tipping Points and Abrupt Climate Change

The term *tipping point* is most typically used, in the context of climate change, 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 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).

[26] Some SO_2 emissions are associated with the charging of EVs. However, total power plant emissions are limited by “caps” under the EPA Acid Rain Program and the Cross-State Air Pollution Rule, and will be reduced through emissions standards such as the Mercury and Air Toxics Standards rule. Because of these rules and advances in technology, emissions from the power-generation sector are expected to decline over time (the grid is expected to become cleaner). Any economic activity or trend that leads to an increase in electrical demand—including increases in electric vehicle sales and use—would be accommodated by the power industry in planning for compliance with applicable emissions limitations.

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 2013a), *Climate Change Impacts in the United States: The Third National Climate Assessment* (GCRP 2014), and *Climate Science Special Report: Fourth National Climate Assessment, Volume 1* (GCRP 2017). 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 an increase in GHG emissions and associated radiative forcing, the current state of science does not allow for quantifying how increased emissions 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 8.6.5.2, *Tipping Points and Abrupt Climate Change*. The analysis applies equally to direct and indirect impacts, as well as Chapter 8*, Cumulative Impacts*.

5.4 Environmental Consequences

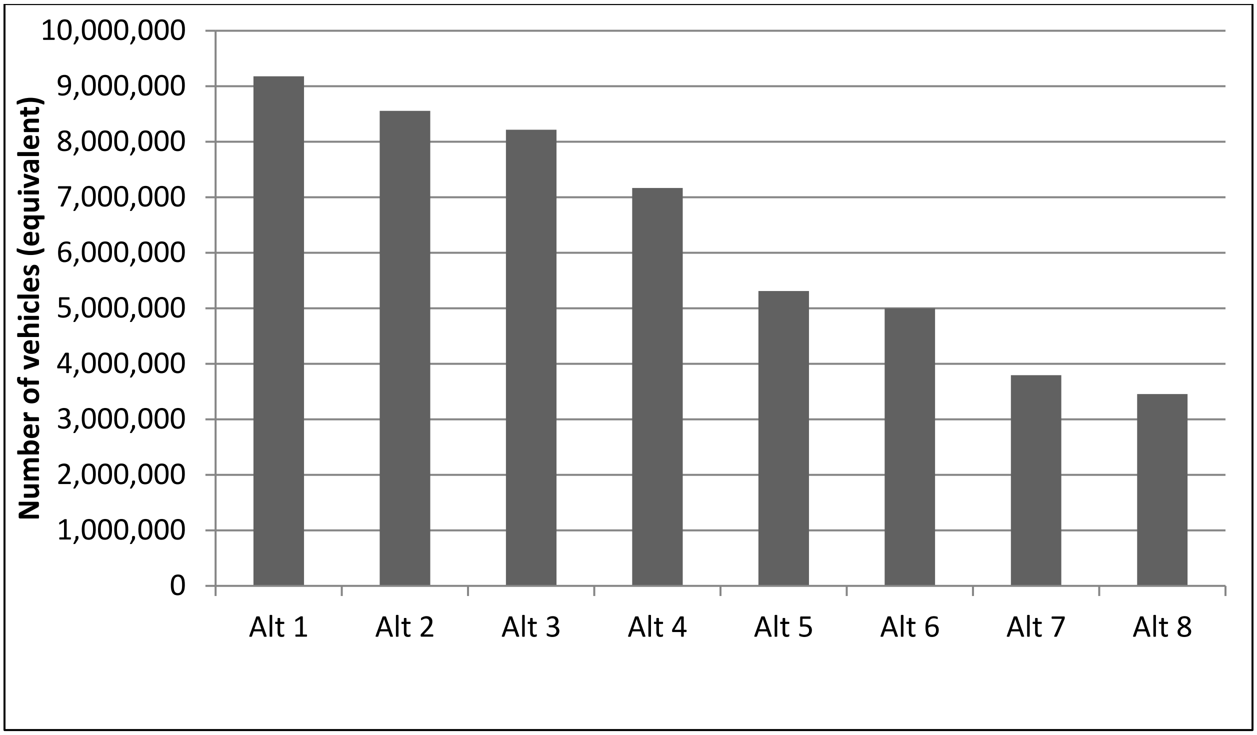
This section describes projected impacts on climate under the Proposed Action and alternatives relative to the No Action Alternative. NHTSA is proposing Alternative 1 as the Preferred Alternative. Using the methods described in Section 5.3, *Analysis Methods*, NHTSA modeled the direct and indirect impacts of the alternatives on atmospheric CO_2 concentrations, temperature, precipitation, sea level, and ocean pH. This analysis is based on a scenario under which no other major global actions would reduce GHGs (i.e., the current climate trajectory, independent of other actions). The analysis of cumulative impacts can be found in Chapter 8, *Cumulative Impacts.*

In summary, each of the action alternatives would result in increased GHG emissions compared with the No Action Alternative. The more an alternative would increase GHG emissions, the more it would be expected to increase the direct and indirect climate change impacts associated with such emissions. However, all of the action alternatives would result, to a greater or lesser extent depending on the alternative, in reductions in GHG emissions on a per-vehicle basis compared with current conditions as newer, more fuel-efficient vehicles replace less fuel-efficient vehicles currently on the road.

5.4.1 Greenhouse Gas Emissions

Using the methods described in Section 5.3, *Analysis Methods*, NHTSA estimated projected emissions increases for 2021 through 2100. These emissions increases represent the differences in total annual emissions in future years of U.S. passenger cars and light trucks in use under the No Action Alternative and each action alternative. 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 increase 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 94 percent. From 2016 to 2027, Alternative 8 would have lower emissions than Alternative 7. However, Alternative 7 would result in lower emissions than Alternative 8 from 2028 to 2100, and would be the lowest emissions alternative from 2021 to 2100.[27]

Figure 5.4.1-1. Number of Passenger Cars and Light Trucks Equivalent to Carbon Dioxide Increases in 2025 Compared to the No Action Alternative



5.4.1.1 Global Carbon Budget

In response to public comments received on prior NHTSA EISs, the agency has considered the GHG impacts of its fuel economy actions in terms of a global carbon "budget." This budget 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 preindustrial levels. IPCC estimates that if cumulative global CO_2 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 (IPCC 2013b).[28] It should be noted that since this report was published, various studies have produced estimates of the remaining global carbon budget; some estimates have been larger (Millar et al. 2017) and others have been smaller (Lowe and Bernie 2018). These estimates vary depending on a range of factors, such as the assumed conditions and the climate model used. Because

[27] The passenger car and light truck 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 passenger car and light truck accounts for 3.87 metric tons of CO_2 in 2025 based on MOVES, the GREET model, and EPA analysis.

[28] Factoring in non-CO_2 influences on the climate, the global carbon budget is approximately 790 Gt C (2,900 Gt CO_2). As of 2011, approximately 65 percent, or 515 Gt C (1,890 Gt CO_2) of this budget had already been emitted, leaving a remaining budget of 275 Gt C (1,010 Gt CO_2) (IPCC 2013b). From 2011 to 2015, CO_2 emissions from fossil fuels, cement production, and land-use change totaled approximately 50 Gt C, leaving a remaining budget from 2016 onwards of 225 Gt C, including non-CO_2 influences (CDIAC 2016).

of underlying uncertainties and assumptions, no one number for the remaining global carbon budget can be considered definite.

Using the IPCC estimated carbon budget, 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). From 2011 to 2015, CO_2 emissions from fossil fuels, cement production, and land-use change totaled approximately 50 Gt C (183 Gt CO_2), leaving a remaining budget from 2016 onwards of 435 Gt C (1595 Gt CO_2) (CDIAC 2016). Under the No Action Alternative, U.S. passenger cars and trucks are projected to emit 23 Gt C (83 Gt CO_2) from 2016 to 2100, or 5.2 percent of the remaining global carbon budget. Under Alternative 1, this projection increases to 25 Gt C (91 Gt CO_2) or 5.7 percent of the remaining budget.

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. passenger car and light truck 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 passenger car and light truck 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 the economy and the vehicle fleet to substantially move away from the use of fossil fuels, which is not currently technologically feasible or economically practicable.

5.4.2 Direct and Indirect Impacts on Climate Change Indicators

The direct and indirect impacts of the Proposed Action and alternatives on five relevant climate change indicators are described in Section 5.4.2.1, *Atmospheric Carbon Dioxide Concentrations*; Section 5.4.2.2, *Temperature*; Section 5.4.2.3, *Precipitation*; Section 5.4.2.4, *Sea-Level Rise*; and Section 5.4.2.5, *Ocean pH*. Section 5.4.2.6, *Climate Sensitivity Variations*, presents the sensitivity analysis. The impacts of the Proposed Action and alternatives on global mean surface temperature, atmospheric CO_2 concentrations, precipitation, sea level, and ocean pH would be 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 climate change. Although these effects are small, they occur on a global scale and are long-lasting. The combined impact of these emissions increases with emissions increases from other sources could have health, societal, and environmental impacts.

MAGICC6 is a reduced-complexity climate model well calibrated to the mean of the multi-model ensemble results for four of the most commonly used emissions scenarios—RCP2.6 (low), RCP4.5 (medium), RCP6.0 (medium-high), and RCP8.5 (high) from the IPCC RCP series—as shown in

Table 5.4.2-1.[29] 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.

Table 5.4.2-1. Comparison of MAGICC Modeling Results and Reported IPCC Results[a]

Scenario	CO_2 Concentration (ppm)		Global Mean Increase in Surface Temperature (°C)	
	IPCC WGI (2100)	MAGICC (2100)	IPCC WGI (2081—2100)	MAGICC (2100)
RCP2.6	421	426	1.0	1.1
RCP4.5	538	544	1.8	2.1
RCP6.0	670	674	2.2	2.6
RCP8.5	936	938	3.7	4.2

Notes:
[a] The IPCC values represent the average of the 5 to 95 percent range of global mean surface air temperature.
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
Source: IPCC 2013a

As discussed in Section 5.3.1, *Methods for Modeling Greenhouse Gas Emissions*, NHTSA used the GCAM Reference scenario to represent the No Action Alternative in the MAGICC modeling runs. CO_2 concentrations under the No Action Alternative are 789.11 ppm and range from 789.27 under Alternative 7 to 789.76 ppm under Alternative 1 in 2100 (Table 5.4.2-2). For 2040 and 2060, the corresponding range of ppm differences across alternatives is even smaller. Because CO_2 concentrations are the key determinant of other climate effects (which in turn drive the resource impacts discussed in Section 8.6, *Cumulative Impacts—Greenhouse Gas Emissions and Climate Change*), this leads to very small differences in these effects.

Table 5.4.2-2. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, Sea-Level Rise, and Ocean pH (GCAM Reference) by Alternative[a]

	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b, c]			Sea-Level Rise (cm)[b, d]			Ocean pH[e]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100	2040	2060	2100
Totals by Alternative												
Alt. 0—No Action	479.04	565.44	789.11	1.287	2.008	3.484	22.87	36.56	76.28	8.4099	8.3476	8.2176
Alt. 1	479.15	565.73	789.76	1.288	2.010	3.487	22.87	36.58	76.34	8.4098	8.3474	8.2173
Alt. 2	479.14	565.71	789.72	1.288	2.010	3.487	22.87	36.57	76.33	8.4098	8.3474	8.2173
Alt. 3	479.14	565.70	789.68	1.288	2.009	3.486	22.87	36.57	76.33	8.4098	8.3474	8.2173
Alt. 4	479.12	565.66	789.60	1.287	2.009	3.486	22.87	36.57	76.32	8.4098	8.3474	8.2173
Alt. 5	479.10	565.61	789.48	1.287	2.009	3.486	22.87	36.57	76.31	8.4099	8.3475	8.2174
Alt. 6	479.09	565.57	789.40	1.287	2.009	3.485	22.87	36.57	76.31	8.4099	8.3475	8.2174
Alt. 7	479.07	565.52	789.27	1.287	2.009	3.485	22.87	36.57	76.30	8.4099	8.3475	8.2175
Alt. 8	479.08	565.54	789.32	1.287	2.009	3.485	22.87	36.57	76.30	8.4099	8.3475	8.2175

[29] NHTSA used the MAGICC default climate sensitivity of 3.0 °C (5.4 °F).

	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b, c]			Sea-Level Rise (cm)[b, d]			Ocean pH[e]		
	2040	2060	2100	2040	2060	2100	2040	2060	2100	2040	2060	2100
Increases Under Proposed Action and Alternatives												
Alt. 1	0.11	0.29	0.65	0.001	0.001	0.003	0.00	0.01	0.06	0.0001	0.0002	0.0003
Alt. 2	0.11	0.27	0.61	0.001	0.001	0.003	0.00	0.01	0.05	0.0001	0.0002	0.0003
Alt. 3	0.10	0.25	0.57	0.000	0.001	0.002	0.00	0.01	0.05	0.0001	0.0002	0.0003
Alt. 4	0.09	0.22	0.50	0.000	0.001	0.002	0.00	0.01	0.04	0.0001	0.0001	0.0002
Alt. 5	0.07	0.17	0.37	0.000	0.001	0.002	0.00	0.01	0.03	0.0001	0.0001	0.0002
Alt. 6	0.05	0.13	0.29	0.000	0.001	0.001	0.00	0.01	0.03	0.0000	0.0001	0.0001
Alt. 7	0.03	0.07	0.16	0.000	0.000	0.001	0.00	0.00	0.01	0.0000	0.0000	0.0001
Alt. 8	0.04	0.10	0.21	0.000	0.000	0.001	0.00	0.00	0.02	0.0000	0.0001	0.0001

Notes:

[a] The numbers in this table have been rounded for presentation purposes. As a result, the increases 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 to 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.

[e] Ocean pH changes reported as 0.0000 are more than zero but less than 0.0001.

CO_2 = carbon dioxide; °C = degrees Celsius; ppm = parts per million; cm = centimeters; GCAM = Global Change Assessment Model

5.4.2.1 Atmospheric Carbon Dioxide Concentrations

As Figure 5.4.2-1 and Figure 5.4.2-2 show, the increase in projected CO_2 concentrations under the Proposed Action and alternatives compared to the No Action Alternative amounts to a very small fraction of the projected total increases in CO_2 concentrations. The relative impact of the Proposed Action and alternatives is demonstrated by the increase of CO_2 concentrations under the range of action alternatives. As shown in Figure 5.4.2-2, the increase in CO_2 concentrations by 2100 under Alternative 1 compared to the No Action Alternative is more than three times that of Alternative 7.

Figure 5.4.2-1. Atmospheric Carbon Dioxide Concentrations by Alternative

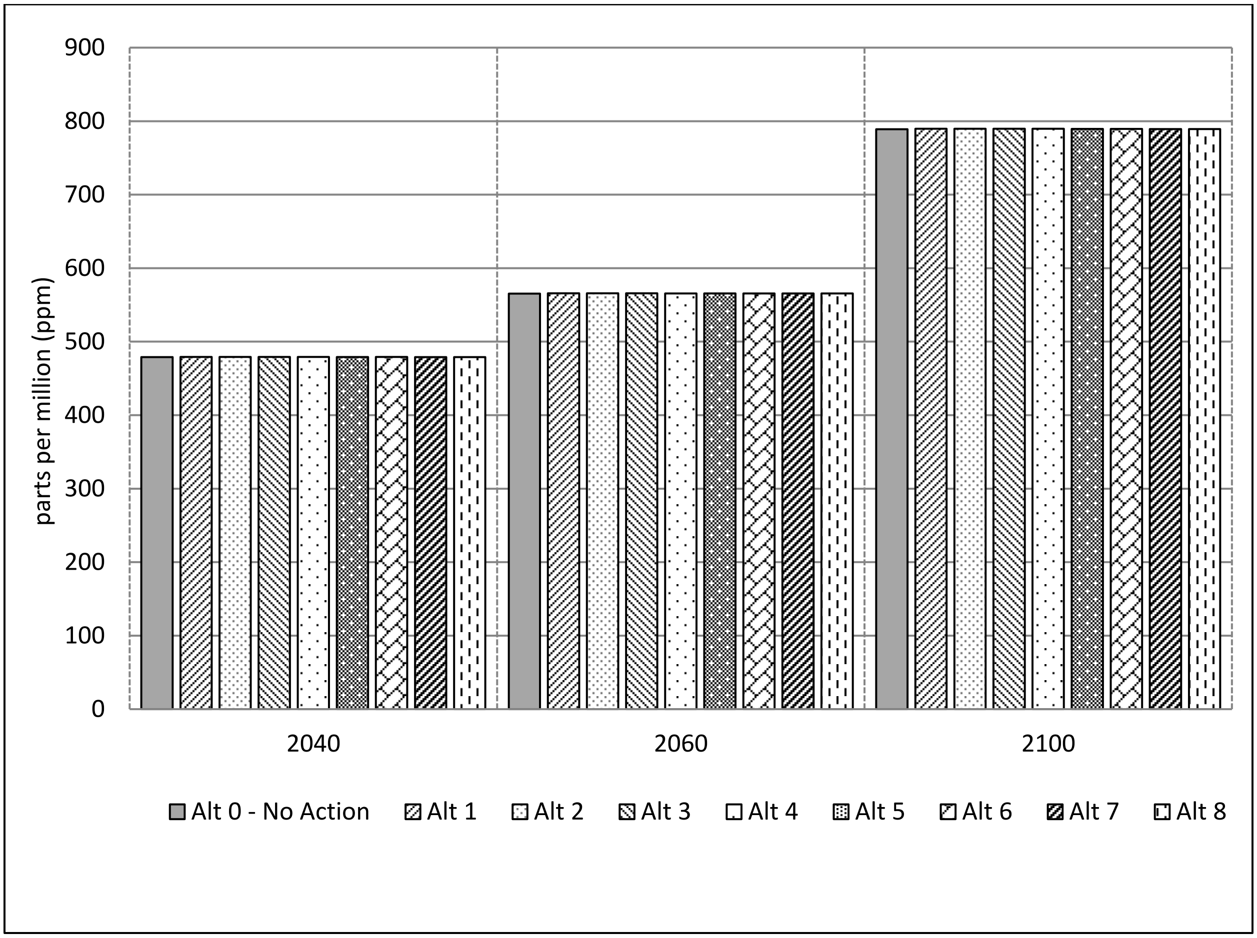
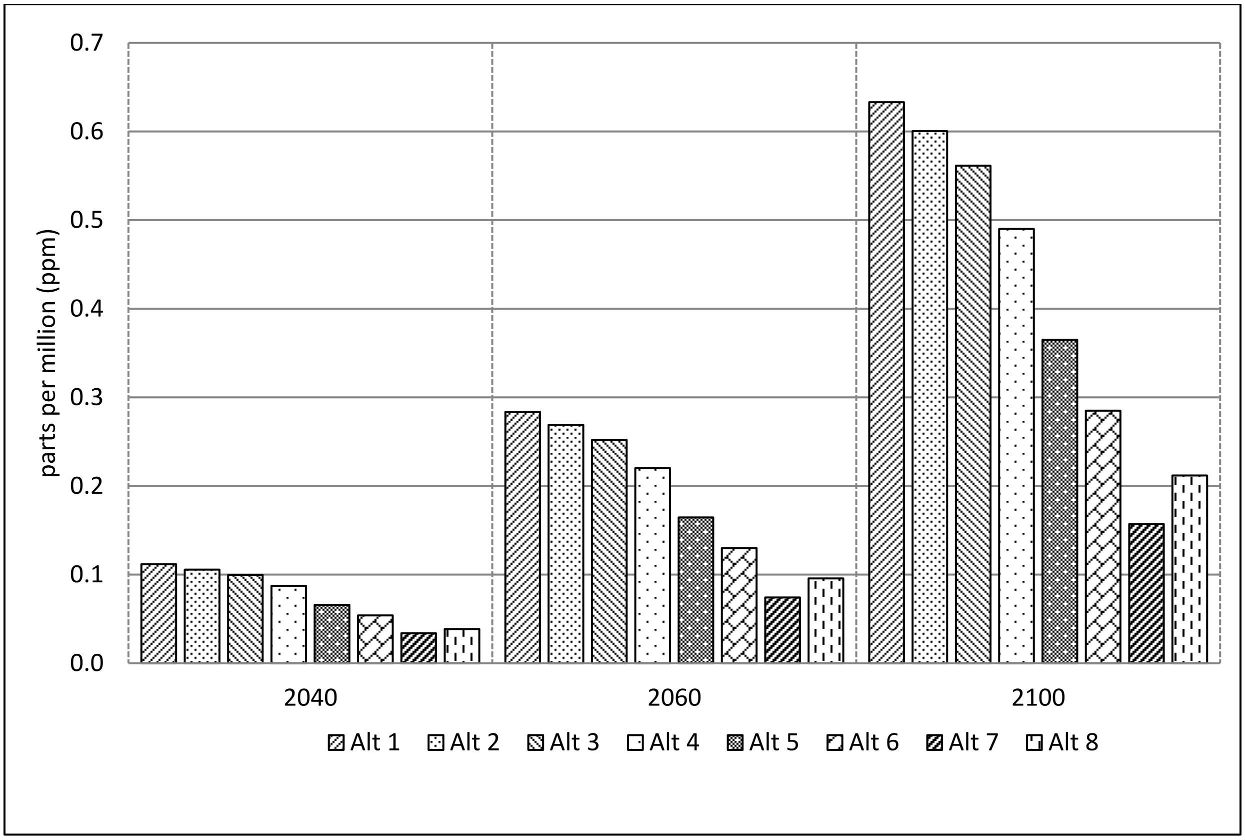


Figure 5.4.2-2. Increase in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative



5.4.2.2 Climate Change Attributes

Temperature

Table 5.4.2-2 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 to 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.[30] The differences among the increases in baseline temperature increases projected to result from the various action alternatives are very small compared to total projected temperature increases, which are shown in Figure 5.4.2-3. For example, in 2100 the increase in temperature rise compared to the No Action Alternative ranges from 0.001°C (0.002°F) under Alternative 7 to 0.003°C (0.006°F) under Alternative 1.

[30] Because the actual increase in global mean surface temperature lags the "commitment to warming" (i.e., continued warming from GHGs that have already been emitted to date, because of the slow response of the climate system), 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 5.4.2-3. Global Mean Surface Temperature Increase by Alternative

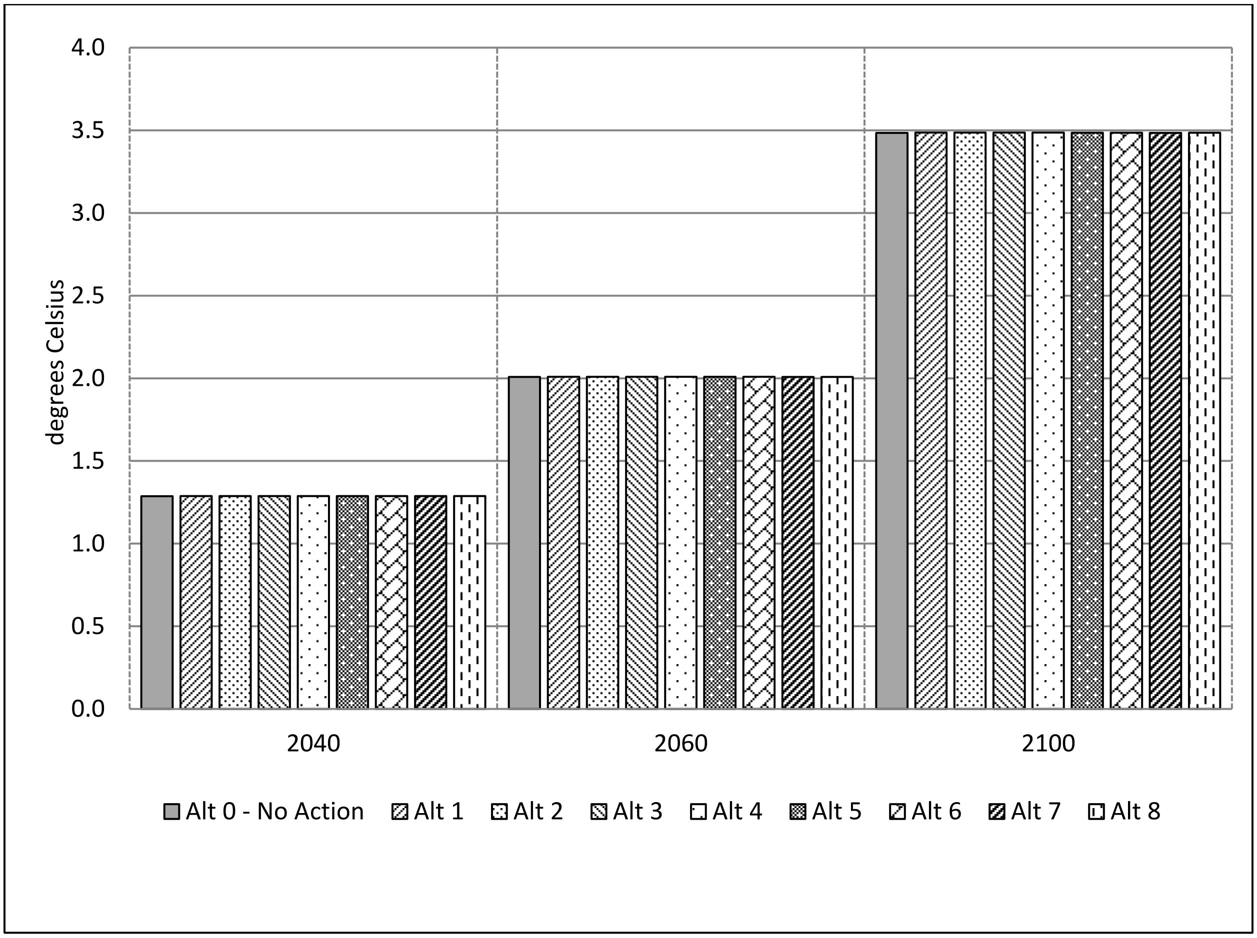


Figure 5.4.2-4 also illustrates that increases in the growth of projected global mean surface temperature under the Proposed Action and alternatives compared to the No Action Alternative are anticipated to be small compared to total projected temperature increases. However, the relative impacts of the Proposed Action and alternatives can be seen by comparing the increases in the rise in global mean surface temperature projected to occur under Alternatives 1 and 7. As shown in Figure 5.4.2-4, the increase in the projected growth in global temperature under Alternative 1 is more than three times as large as that under Alternative 7 in 2100.

Figure 5.4.2-4. Increase in Global Mean Surface Temperature Compared to the No Action Alternative

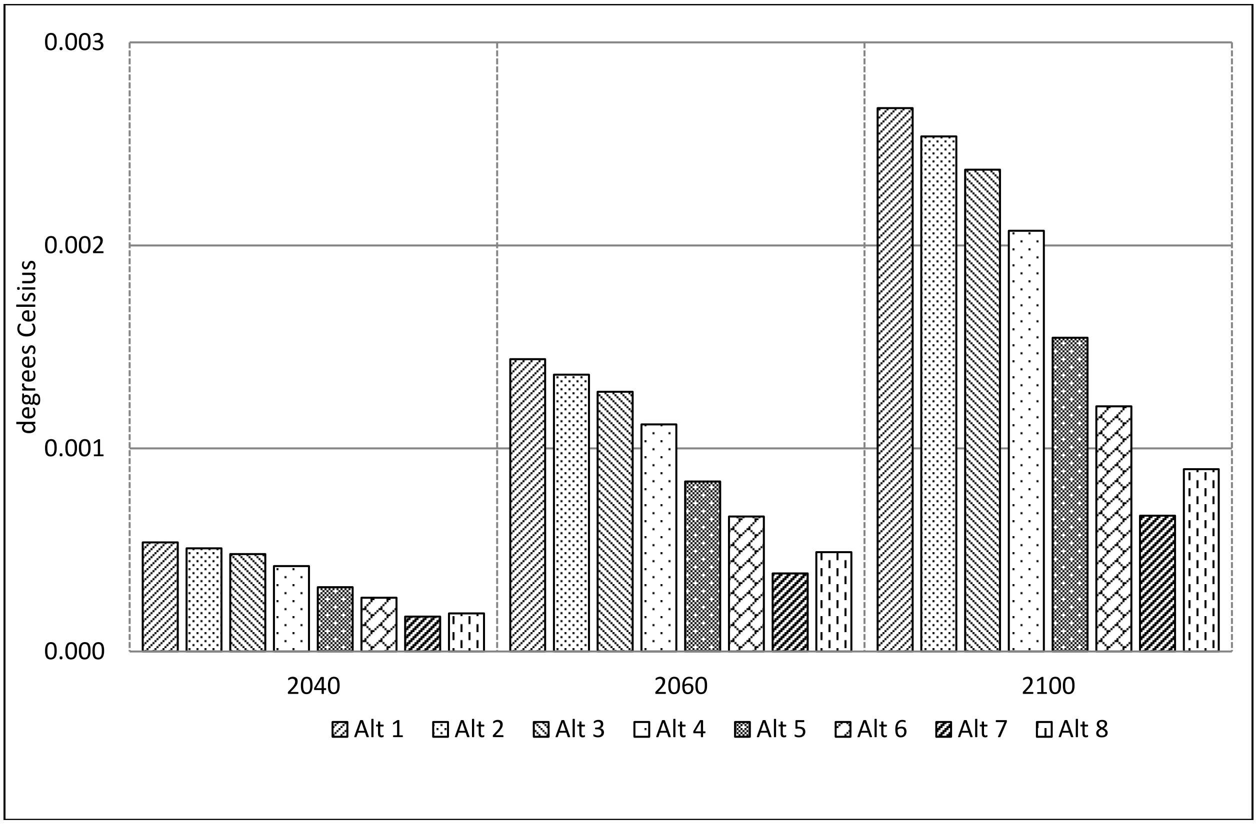


Table 5.4.2-3 summarizes the regional changes in warming and seasonal temperatures presented in the IPCC Fifth Assessment Report (AR5). At this time, quantifying the changes in regional climate because of the Proposed Action and alternatives is not possible because of the limitations of existing climate models, but the Proposed Action and alternatives would be expected to increase the regional impacts in proportion to increases in global mean surface temperature.

Table 5.4.2-3. 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	--
	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

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
	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
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

Land Area	Subregion	Mean Warming	Other Impacts on Temperature
	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
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 2013a

Sea-Level Rise

IPCC identifies five primary components of sea-level rise: thermal expansion of ocean water, melting of glaciers and ice caps, loss of land-based ice in Antarctica, loss of land-based ice in Greenland, and contributions from anthropogenic impacts on water storage (e.g., extraction of groundwater) (IPCC 2013a). 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 AR5 (IPCC 2013a) projects the mean sea-level rise for each of the RCP scenarios. As noted in Section 5.3.3.2, *Sea Level Rise,* 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 2013a). Sea-level rise projections in the IPCC AR5 are substantially higher than projections in the IPCC AR4 because they include significant contributions of melting from large ice sheets (in particular, Greenland and Antarctica) and mountain glaciers. 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 2013a). However, IPCC results for sea-level projections are still lower than results 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 Section 5.1.5, *Future Climate Trends and Expected Impacts*, and Section 5.3.3.2, *Sea-Level Rise*, for more information on sea-level rise.

Table 5.4.2-2 lists the impacts of the Proposed Action and 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 between 76.34 centimeters (30.06 inches) under Alternative 1 and 76.30 centimeters (30.04 inches) under Alternative 7. This represents a maximum increase of 0.06 centimeter (0.02 inch) by 2100 under Alternative 1 compared to the No Action Alternative.

Precipitation

In some areas, the increase in energy available to the hydrologic cycle is expected to 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 2013a), 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 subtropics (EPA 2009).

MAGICC does not directly simulate changes in precipitation, and NHTSA has not undertaken precipitation modeling with a full AOGCM. However, the IPCC (IPCC 2013a) summary of precipitation represents the most thoroughly reviewed, credible means of producing an assessment of this highly uncertain factor. NHTSA expects that the Proposed Action and alternatives would increase anticipated changes in precipitation (i.e., in a reference case with no GHG emissions reduction policies) in proportion to the impacts of the alternatives on temperature.

The global mean change in precipitation provided by IPCC for the RCP8.5 (high), RCP6.0 (medium-high), RCP4.5 (medium) and RCP2.6 (low) scenarios (IPCC 2013a) 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 5.4.2-4. 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 watts per square meter, similar to the GCAM Reference scenario's radiative forcing of 7 watts per square meter) in this analysis because MAGICC does not directly estimate changes in global mean precipitation.

Table 5.4.2-4. 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

Source: Figure 12-7 in IPCC 2013a

Applying these scaling factors to the increases in global mean surface warming provides estimates of changes in global mean precipitation. The Proposed Action and alternatives are projected to increase temperature rise and predicted increases in precipitation slightly compared to the No Action Alternative, as shown in Table 5.4.2-5 (based on the scaling factor from the RCP6.0 scenario); however, the increase in precipitation is less than 0.005 percent and thus is rounded to 0.00 percent in the table.

Table 5.4.2-5. Global Mean Precipitation (Percent Increase) Based on GCAM Reference Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative[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. 0—No Action	1.287	2.008	3.484
Alt. 1	1.288	2.010	3.487
Alt. 2	1.288	2.010	3.487
Alt. 3	1.288	2.009	3.486
Alt. 4	1.287	2.009	3.486
Alt. 5	1.287	2.009	3.486
Alt. 6	1.287	2.009	3.485
Alt. 7	1.287	2.009	3.485
Alt. 8	1.287	2.009	3.485
Increases in Global Temperature (°C) by Alternative, (Compared to the No Action Alternative)[b]			
Alt. 1	0.001	0.001	0.003
Alt. 2	0.001	0.001	0.003
Alt. 3	0.000	0.001	0.002
Alt. 4	0.000	0.001	0.002
Alt. 5	0.000	0.001	0.002
Alt. 6	0.000	0.001	0.001
Alt. 7	0.000	0.000	0.001
Alt. 8	0.000	0.000	0.001
Global Mean Precipitation Increase by Alternative (%)			
Alt. 0—No Action	2.16%	3.37%	5.85%
Alt. 1	2.16%	3.38%	5.86%

Scenario	2040	2060	2100
Alt. 2	2.16%	3.38%	5.86%
Alt. 3	2.16%	3.38%	5.86%
Alt. 4	2.16%	3.38%	5.86%
Alt. 5	2.16%	3.38%	5.86%
Alt. 6	2.16%	3.37%	5.86%
Alt. 7	2.16%	3.37%	5.85%
Alt. 8	2.16%	3.37%	5.85%
Increase in Global Mean Precipitation Increase by Alternative (% Compared to the No Action Alternative)			
Alt. 1	0.00%	0.00%	0.00%
Alt. 2	0.00%	0.00%	0.00%
Alt. 3	0.00%	0.00%	0.00%
Alt. 4	0.00%	0.00%	0.00%
Alt. 5	0.00%	0.00%	0.00%
Alt. 6	0.00%	0.00%	0.00%
Alt. 7	0.00%	0.00%	0.00%
Alt. 8	0.00%	0.00%	0.00%

Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the increases 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.
[c] The increase in precipitation is less than 0.005%, and thus is rounded to 0.00%.
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.[31] 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 Proposed Action and alternatives) would produce results that would be difficult to resolve among scenarios. In addition, the multiple AOGCMs produce results regionally consistent in some cases but inconsistent in others.

Table 5.4.2-6 summarizes, in qualitative terms, the regional changes in precipitation from the IPCC AR5. Quantifying the changes in regional climate under the Proposed Action and alternatives is not possible at this time, but the action alternatives would be expected to increase the relative precipitation changes in proportion to the increase in global mean surface temperature.

[31] 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."

Table 5.4.2-6. 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 and Mediterranean	*Likely* decrease in summer 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

Land Area	Sub-region	Precipitation	Snow Season and Snow Depth
	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	
Polar Regions	Arctic	*Likely* increase in precipitation	--
	Antarctic	*Likely* increase in precipitation	
Small Islands	--	Rainfall *likely* to increase over certain regions	

Notes:
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
Source: IPCC 2013a

Ocean pH

As Table 5.4.2-2 shows, the decrease of projected ocean pH under the Proposed Action and alternatives compared to the No Action Alternative amounts to a small portion of the projected total decrease in ocean pH due to global CO_2 emissions. The relative impact of the action alternatives is demonstrated by the decrease of ocean pH under the range of action alternatives. As shown in Table 5.4.2-2, the decrease of ocean pH by 2100 under Alternative 1 is more than three times that of Alternative 7.

5.4.2.3 Climate Sensitivity Variations

Using the methods described in Section 5.3.3.6, *Sensitivity Analysis*, 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 using the GCAM Reference scenario.

Table 5.4.2-7 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 preindustrial atmospheric concentrations (278 ppm CO_2) (Section 5.3.3.6, *Sensitivity Analysis*).

Table 5.4.2-7. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise, and Ocean pH for Varying Climate Sensitivities for Selected Alternatives[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]	Ocean pH
		2040	2060	2100	2040	2060	2100	2100	2100
Alt. 0—No Action	1.5	469.61	546.10	737.48	0.741	1.128	1.890	41.05	8.2445
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	52.74	8.2350
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	64.52	8.2260
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	76.28	8.2176
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	110.93	8.1952
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	144.70	8.1759
Alt. 1	1.5	469.72	546.38	738.08	0.741	1.129	1.892	41.07	8.2442
	2.0	473.20	553.38	756.11	0.942	1.447	2.453	52.78	8.2346
	2.5	476.33	559.81	773.32	1.123	1.740	2.983	64.57	8.2257
	3.0	479.15	565.73	789.76	1.288	2.010	3.487	76.34	8.2173
	4.5	486.11	580.92	835.00	1.699	2.709	4.872	111.02	8.1949
	6.0	491.46	593.18	875.61	2.020	3.281	6.176	144.82	8.1756
Alt. 7	1.5	469.64	546.17	737.63	0.741	1.128	1.891	41.05	8.2444
	2.0	473.13	553.17	755.64	0.941	1.446	2.451	52.75	8.2349
	2.5	476.25	559.59	772.84	1.123	1.739	2.982	64.53	8.2259
	3.0	479.07	565.52	789.27	1.287	2.009	3.485	76.30	8.2175
	4.5	486.03	580.70	834.45	1.699	2.707	4.869	110.96	8.1951
	6.0	491.38	592.95	875.07	2.020	3.280	6.173	144.73	8.1759
Increase Under Alt. 1 Compared to No Action Alternative									
Alt. 1	1.5	0.11	0.28	0.60	0.000	0.001	0.002	0.03	0.0003
	2.0	0.11	0.28	0.62	0.000	0.001	0.002	0.04	0.0003
	2.5	0.11	0.29	0.64	0.000	0.001	0.002	0.05	0.0003

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[b]	Ocean pH
		2040	2060	2100	2040	2060	2100	2100	2100
	3.0	0.11	0.29	0.65	0.001	0.001	0.003	0.06	0.0003
	4.5	0.11	0.30	0.72	0.001	0.002	0.004	0.09	0.0004
	6.0	0.11	0.30	0.73	0.001	0.002	0.005	0.12	0.0003
Increase Under Alt. 7 Compared to No Action Alternative									
Alt. 7	1.5	0.03	0.07	0.15	0.000	0.000	0.000	0.01	0.0001
	2.0	0.03	0.07	0.15	0.000	0.000	0.000	0.01	0.0001
	2.5	0.03	0.07	0.16	0.000	0.000	0.001	0.01	0.0001
	3.0	0.03	0.07	0.16	0.000	0.000	0.001	0.01	0.0001
	4.5	0.03	0.08	0.17	0.000	0.000	0.001	0.02	0.0001
	6.0	0.03	0.08	0.19	0.000	0.001	0.001	0.03	0.0001

Notes:
[a] The numbers in this table have been rounded for presentation purposes. As a result, the increases 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.
ppm = parts per million; °C = degrees Celsius; CO_2 = carbon dioxide; cm = centimeters

As the tables show, varying climate sensitivities (the equilibrium warming that occurs at a doubling of CO_2 from preindustrial levels) can affect not only estimated warming, but also estimated sea-level rise, ocean pH, and atmospheric CO_2 concentration. This complex set of interactions occurs because both atmospheric CO_2 and temperature affect ocean absorption of atmospheric CO_2, which reduces ocean pH. Specifically, higher temperatures result in lower aqueous solubility of CO_2, while higher concentrations of atmospheric CO_2 lead to more ocean absorption of CO_2. Atmospheric CO_2 concentrations are affected by the amount of ocean carbon storage. Therefore, as Table 5.4.2-7 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. Regardless of the climate sensitivity used in the model, increases in global CO_2 concentrations under the Proposed Action and alternatives would be very small compared to total projected increases in global CO_2 concentrations.

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 5.4.2-7. 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 increase in 2100 global mean surface temperature from the No Action Alternative to Alternative 1 ranges from 0.002°C (0.004°F) for the 1.5°C (2.7°F) climate sensitivity to 0.005°C (0.009°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 5.4.2-7. Scenarios with lower climate sensitivities show generally smaller increases in sea-level rise; at the same time, sea-level rise is higher under the Proposed Action and alternatives compared to the No Action Alternative. Conversely, scenarios with higher climate sensitivities have higher projected sea-level rise; again, however, sea-level rise is higher under the Proposed Action and alternatives compared to the No Action Alternative. The range in increase of sea-level rise under Alternative 1 compared to the No Action Alternative is 0.03 to 0.12 centimeter (0.012 to 0.047 inch), depending on the assumed climate sensitivity.

CHAPTER 6 LIFE-CYCLE ASSESSMENT OF VEHICLE ENERGY, MATERIAL, AND TECHNOLOGY IMPACTS

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 phase of a vehicle’s life cycle, including production of fuel for vehicle use, contributes to greenhouse gas (GHG) emissions, energy use, and other environmental impacts.

Life-cycle considerations are already included in other analyses in this EIS. For example, air quality and climate impacts reported in Chapter 4, *Air Quality,* and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, include upstream emissions from the following sources:

- Feedstock extraction.
- The use, leakage, spillage, flaring, and evaporation of fuels during feedstock production (e.g., crude oil or natural gas).
- Feedstock transportation (to refineries or processing plants).
- Fuel refining and processing (into gasoline, diesel, dry natural gas, and natural gas liquids).
- Refined product transportation (from bulk terminals to retail outlets).
- Electricity generation.

These upstream emissions account for around 20 percent of total GHG emissions from passenger car and light truck fuel use and 1 to 96 percent of non-GHG emissions from passenger car and light truck fuel use, depending on the specific pollutant. Air quality and climate impacts reported in Chapter 4, *Air Quality,* and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, 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 passenger car and light truck materials or technologies 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 data collection on many variables that are highly uncertain, such as the following variables:

- The future response of passenger car and light truck manufacturers to the MY 2021–2026 fuel economy standards.
- The specific design of multiple fuel efficiency technologies and their manufacture, application to vehicles, and disposal after use.
- Interactions between applications of those technologies.
- Regional fuel sourcing projections.
- Primary data on the variety of vehicle types, manufacturers, and uses expected in the future.

The Proposed Action and alternatives are based on performance and do not mandate the adoption of specific technologies. As a result, NHTSA does not know precisely how manufacturers will choose from a suite of available technologies to meet standards. In addition, manufacturing and disposal processes may change over time and are beyond the scope of NHTSA's capabilities to predict and effectively analyze. NHTSA is unable to differentiate between the alternatives in this chapter. Rather than aid in the selection of an alternative, the intent of this chapter is to understand the life-cycle implications of vehicles, particularly the upstream emissions associated with electricity generation for electric vehicles and potential changes in types of materials used in an effort to reduce vehicle weight. This information is helpful to the decision-maker in the specific context of this rulemaking, where manufacturers could employ a suite of technology options, with different potential environmental impacts, in meeting the proposed standards. Therefore, this chapter focuses on existing credible scientific information to evaluate the most significant environmental impacts from some of the fuels, materials, and technologies that may be used to comply with the Proposed Action and alternatives.

This literature synthesis in this chapter is divided into the following sections:

- Section 6.1, *Introduction*, provides background on applying LCA methods to passenger cars and light trucks.
- Section 6.2, *Energy Sources*, examines LCA impacts associated with different passenger car and light truck fuels.
- Section 6.3, *Materials and Technologies,* examines LCA impacts associated with passenger car and light truck materials and technologies.
- Section 6.4, *Conclusions*, presents conclusions from this research synthesis.

This chapter does not attempt to provide a comprehensive review of all LCA studies related to passenger cars and light trucks. 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 those chapters. This literature synthesis supplements the quantitative analysis of the Proposed Action and alternatives reported in Chapters 4 and 5.

6.1.1 Life-Cycle Assessment for Vehicles

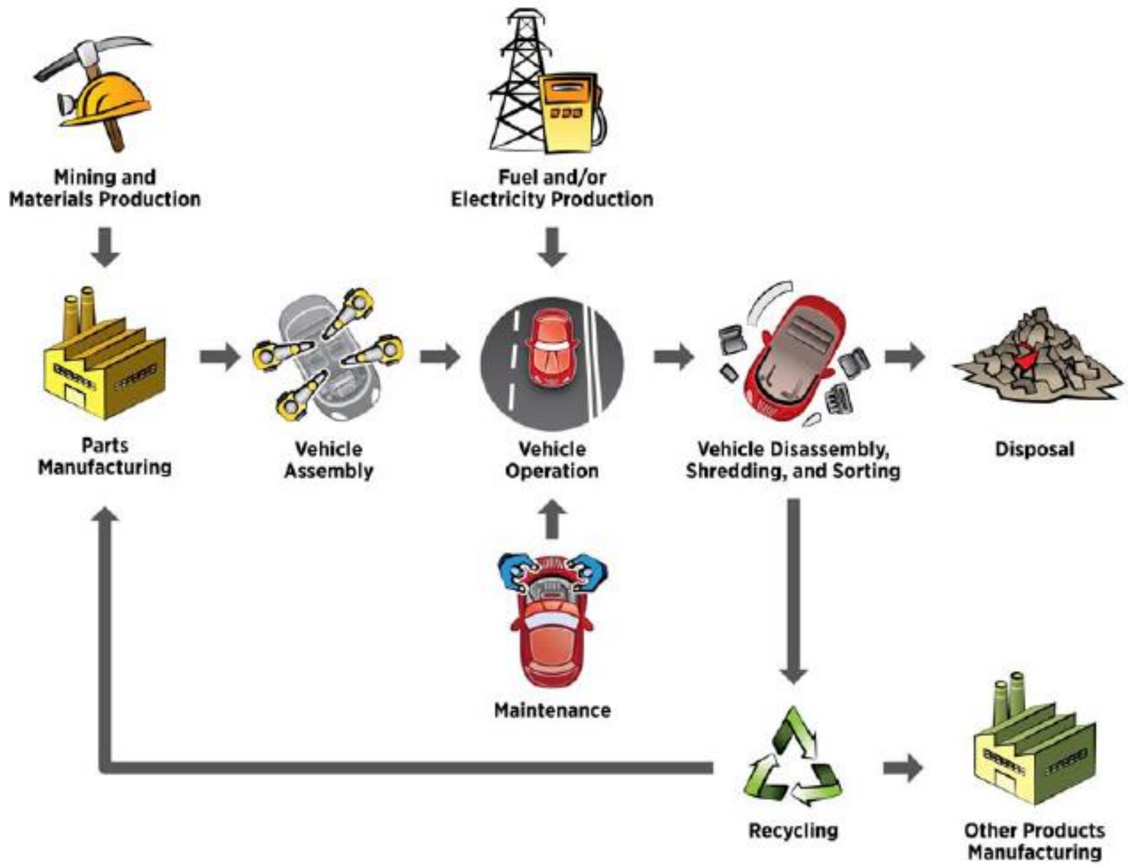
Activities at each phase of a vehicle's life cycle contribute to GHG emissions, energy use, and other environmental impacts. For example, mining and transporting ore requires energy (usually in the form of fossil fuels), as does transforming ore into metal, shaping the metal into parts, assembling the 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 recycling processes require energy and produce emissions. Vehicle LCAs typically evaluate environmental impacts associated with five primary phases:

- **Raw-material extraction.** Extraction includes the mining and sourcing of material and fuel inputs.
- **Manufacturing.** Manufacturing can be identified by phases, such as material and part production and vehicle assembly.
- **Vehicle use.** Use typically consists of two phases: the vehicle operations (e.g., fuel supply and consumption) and maintenance (e.g., part repair or replacement).

- **End-of-life management.** Steps in this phase can include parts recovery, disassembly, shredding, recycling, and landfilling.
- **Transportation.** Materials and product are moved between these various phases.

Figure 6.1.1-1 shows a general example of a light-duty vehicle's life cycle.

Figure 6.1.1-1. Light-Duty Vehicle Life Cycle



Source: NHTSA 2012

An LCA study can help identify major sources of environmental impacts throughout a vehicle's life cycle, and it can identify opportunities for impact mitigation. LCA is useful for examining and comparing vehicle alternatives or specific elements within vehicles. For example, analysts often assess whether certain materials and technologies save energy over the entire life cycle of vehicles, holding other factors (e.g., miles traveled, tons of freight carried, vehicle life) constant. Changes in the material composition of vehicles could decrease potential emissions during vehicle use but increase them during raw material extraction and manufacturing (Geyer 2008). Because a high proportion of total emissions occur during the vehicle's use, the fuel-saving benefits from improved fuel economy often 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, data availability, 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 analysis evaluate different types of passenger cars and light trucks with different assumptions for vehicle weight, vehicle life, and miles traveled which influence the final study results.

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 and time often influence the boundaries and impacts included. LCA practitioners decide how to assign or allocate environmental impacts between the product under study and other products produced by the system.[1] For example, scrap material can perform functions after its use in a vehicle. Studies that consider scrap flows outside the vehicle life-cycle boundary might account for it in the following ways:

- Allocating a portion of the impacts associated with vehicle manufacture or recycling to the scrap flow.
- Treating scrap as a waste flow and not allocating any impacts to it.
- Expanding 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 addressed life-cycle implications using study-specific models developed from life-cycle inventory data sources such as the ecoinvent database.[2] The most commonly used model in the surveyed literature is the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, a public-domain model developed at Argonne National Laboratory that allows users to estimate life-cycle energy and emissions impacts on a full fuel-cycle and vehicle life-cycle basis (ANL 2016). Argonne National Laboratory 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 are estimates based on information from GREET.

Because LCAs are highly sensitive to design and input assumptions, their impact results vary. When comparing and synthesizing studies, this chapter identifies which assumptions influence variability in

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[1] ISO advises that LCAs avoid allocation by dividing the process into separate production systems or through system expansion, including the additional coproduct functions (ISO 2006).

[2] 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.

studies. The intent is to synthesize the key existing and emerging topics in LCA of passenger cars and light trucks, including research challenges and opportunities.

6.1.2 Life-Cycle Assessment Literature

NHTSA identified studies across a range of sources, including academic journals and publications of industry associations and nongovernmental organizations. Appendix C, *Life-Cycle Assessment Studies*, lists all the studies reviewed. Most studies identified were published within the last 10 years. NHTSA prioritized literature published in the last 3 years and LCAs specifically focused on passenger car and light truck technologies. NHTSA incorporates by reference the related LCA literature synthesis for passenger cars and light trucks reported in Chapter 6 of the *Final Environmental Impact Statement for Corporate Average Fuel Economy Standards, Model Years 2017–2025* (the MY 2017–2025 CAFE standards Final EIS) (NHTSA 2012), and for medium- and heavy-duty engines and vehicles reported in Chapter 6 of the *Final Environmental Impact Statement for Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles* (NHTSA 2016c).

Passenger cars and light trucks have many variations and combinations of drivetrain, fuel sources, and other materials/technologies. Passenger car and light truck LCAs commonly include gasoline and diesel powered conventional vehicles, hybrid-electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and flex-fuel vehicles. Each vehicle type is potentially capable of accepting multiple energy or fuel sources in operations. This chapter compares these variations through common functional units. For any LCA, the functional unit represents the basis for which all environmental impacts are quantified to generate results throughout a product's or process's lifetime (ISO 2006). For example, LCA results between vehicle types or life-cycle phases are often communicated in GHG emissions per unit of distance traveled. In this example, the unit of distance is the functional unit. In this chapter, functional units vary based on the specific technology examined but are consistent within specific sections for comparison purposes.

6.2 Energy Sources

In the *Annual Energy Outlook 2018* (AEO 2018) (EIA 2018a), the transportation sector accounted for 78.2 percent of total U.S. petroleum consumption in 2016 and transportation is expected to account for 70.4 percent of U.S. petroleum use in 2040. Passenger cars and light trucks accounted for 56 percent of transportation energy consumption in 2016, and they are expected to account for 44 percent of transportation energy consumption in 2040. Despite a 12.4 percent forecast increase in vehicle miles travelled by passenger cars and light trucks from 2016 to 2040, passenger car and light truck fuel consumption is projected to decrease by 31.4 percent due to increased fuel economy.

Gasoline accounted for 99.4 percent of passenger car and light truck fuel consumption in 2016, and is projected to account for 91.0 percent of consumption in 2040. As illustrated in Table 6.2-1, gasoline is projected to be displaced in part by a projected growth in diesel, E85 ethanol, electricity, and other fuels (e.g., natural gas and hydrogen). (This AEO 2018 forecast reflects projected impacts of augural standards set forth for MYs 2022–2025, and NHTSA does not anticipate the same level of electric vehicle use under the action alternatives considered in this EIS).

Table 6.2-1. Fuel Consumption for Passenger Cars and Light Trucks for 2016 and 2040

Fuel	2016 (%)	2040 (%)
Gasoline	99.4	91.0
Electricity	0.1	3.4
Diesel	0.4	2.3
E85	0.1	2.9
Other fuels	0.1	0.5

Source: EIA 2018a

The AEO 2018 projections represent hypothetical scenarios based on current policies, market prices, resource constraints, and technologies. Broad national and international projections are inherently uncertain and will fail to incorporate major events that generate sudden, unforeseen shifts. Additionally, energy market forecasts are highly uncertain because it is difficult to predict changes in forces that shape these markets, such as changes in technology, demographics, and resources. However, these projections offer opportunities to analyze how different assumptions for variables influence future scenarios (Piotrowski 2016). This section uses the AEO 2018 reference case as a guide in analyzing the most relevant trends for passenger cars and light trucks.

This section synthesizes life-cycle findings on fuel sources for passenger cars and light trucks in Sections 6.2.1, *Diesel and Gasoline*, 6.2.2*, Natural Gas*, 6.2.3, *Electric Vehicles*, 6.2.4, *Biofuels*, and 6.2.5, *Fuel Cells*. The synthesis of LCA studies related to fuel cells is relatively brief because the AEO 2018 does not forecast substantial changes in fuel cell use, and this rulemaking is not expected to have a large impact on the extent of fuel cell use.

6.2.1 Diesel and Gasoline

The LCA studies generally agree that point-of-use fuel emissions account for approximately 75 percent of life-cycle vehicle GHG emissions in conventional internal combustion engine vehicles. Although upstream emissions are associated with conventional oil production and refining, there is less consensus on the LCA impacts of unconventional sources of petroleum, including shale oil produced by advanced well completion processes involving fracturing (fracking) and petroleum from oil sands. The methane emissions from upstream petroleum production and natural gas systems are discussed in Section 6.2.2.1, *Methane Emissions from Oil and Natural Gas*.

Oil sands, also known as tar sands or bituminous sands, are a mixture of sand and clay saturated with a viscous form of petroleum (bitumen). The United States imports oil sands products—primarily diluted bitumen and synthetic crude from Canada (Canadian National Energy Board 2014). Gasoline and diesel refined 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 GHG emissions and environmental impacts. The recent, rapid rise of U.S. shale oil production and declines in crude oil prices have created uncertainty in the growth of oil sands production (Findlay 2016).

A variety of studies have evaluated the well-to-wheels emissions associated with petroleum from oil sands, and have reached a consensus that oil sands petroleum is more GHG-intensive to produce than conventional counterparts, because oil sands petroleum requires more energy to extract and process. Oil sands also 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 of oil sands affects 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 affect 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 and 0.04 grams of carbon dioxide equivalent[3] per megajoule of energy (g CO_2e/MJ), respectively, from *in situ* extraction of oil sands in Alberta.

Shale oil, commonly called tight oil, represents the other major unconventional oil source. Shale oil comes from hydraulic fracturing of porous geologic formations containing oil. The specific processes, equipment, and resources required in hydraulic fracturing operations are discussed in Section 6.2.2.2, *Shale Gas and Hydraulic Fracturing*. In 2016, shale oil represented the largest portion of U.S. oil production (51 percent), totaling 4.56 million barrels per day (EIA 2018a).

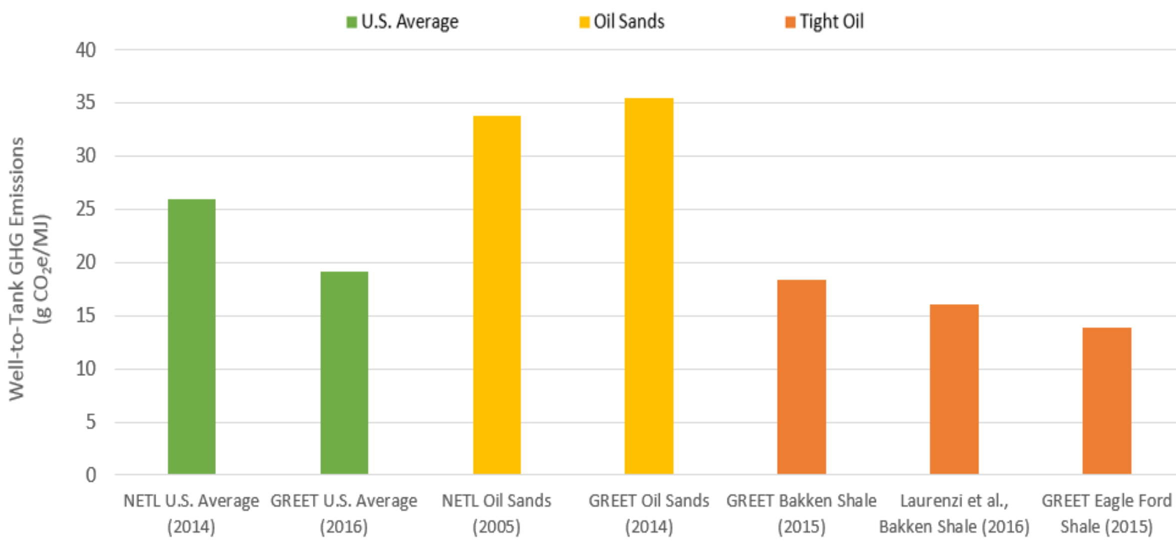
In 2015, the National Energy Technology Laboratory (NETL) published updated estimates of the well-to-tank and well-to-wheels GHG emissions from conventional petroleum fuels produced in the United States, providing comparisons between the original 2005 baseline model and an updated baseline for 2014 (NETL 2015). When comparing the average conventional motor gasoline consumed in the United States in 2014 to the original 2005 estimates, the values show a 70 percent increase in crude extraction emissions, a 31 percent increase in well-to-tank emissions, and a 7 percent increase in well-to-wheels emissions. These changes are the result of several factors, including changes in the crude oil mix and increasing refinery hydrogen demand from the transition to ultra-low sulfur diesel.

Argonne National Laboratory's GREET model provides a snapshot of life-cycle GHG impacts associated with international and domestic conventional petroleum-based fuel pathways. In the model's updates in 2014 and 2015, researchers updated the refinery efficiencies and included values for Canadian oil sands and domestic tight oil from shale based on research at Stanford University and the University of California, Davis (Englander and Brandt 2014, Ghandi et al. 2015, Brandt et al. 2015). GREET's 2016 version uses U.S. Energy Information Administration (EIA) projections for crude oil supplies to generate a default average (63 percent conventional, 18 percent shale oil, 9 percent oil sands) for well-to-tank or well-to-wheels gasoline, as well as enabling the model user to define custom supply profiles.
Figure 6.2.1-1 summarizes the LCA findings for gasoline production from NETL and GREET, including a

[3] Carbon dioxide equivalent (CO_2e) is a measure that expresses the relative global warming potential of greenhouse gas emissions, usually measured over 100 years.

shale oil LCA that focuses on the same Bakken region assessed in the GREET model (Laurenzi et al. 2016).[4]

Figure 6.2.1-1. Well-to-Tank Greenhouse Gas Emissions for Gasoline

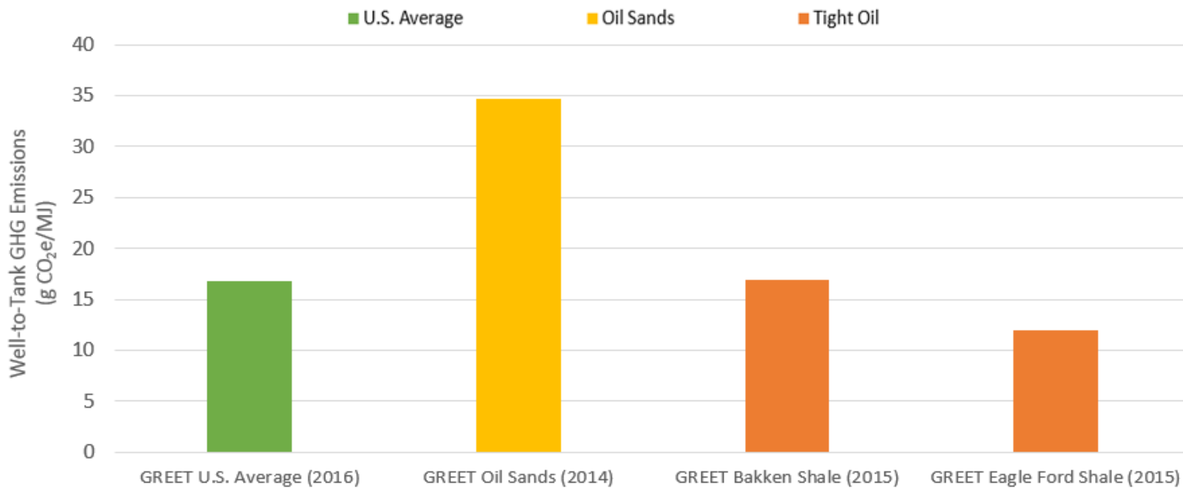


Source: NETL 2015, ANL 2016, Laurenzi et al. 2016
GHG = greenhouse gas; g CO_2e/MJ = grams of carbon dioxide equivalent per megajoule; NETL = National Energy Technology Laboratory; GREET = Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation

Diesel production has similar but slightly lower well-to-tank LCA results than gasoline. Figure 6.2.1-2 shows the variations in diesel emissions from GREET modeling results. The lower well-to-tank results are primarily driven by slightly less overall energy use in diesel refining operations, based on GREET's 2016 simulation of refining processes.

[4] Laurenzi et al. 2016 uses IPCC 5th *National Climate Assessment* (NCA) (AR5) global warming potential factors, while GREET uses 4th NCA (AR4) values. However, those factors have little impact on results, as the CO_2 global warming potential factor is constant in the AR4 and AR5 factors and accounts for the vast majority of well-to-tank GHG emissions.

Figure 6.2.1-2. Well-to-Tank Greenhouse Gas Emissions for Diesel



Source: ANL 2016
GHG = greenhouse gas; g CO_2e/MJ = grams of carbon dioxide equivalent per megajoule; GREET = Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation

The boundaries for the previous two figures are limited to well-to-tank emissions, which is common in LCA literature on transportation fuels. Table 6.2.1-1 presents the CO_2, methane, and nitrous oxide emissions from tank-to-wheels (i.e., vehicle operations) for gasoline and diesel fuels.

Table 6.2.1-1. Estimated Diesel and Gasoline Tank-to-Wheel Emissions (g CO_2e/MJ)

	Carbon Dioxide	Methane[a]	Nitrous Oxide[a]	CO_2e Totals
Diesel	74.9	0.027	0.0002	75.6
Gasoline	72.7	0.002	0.002	73.2

Source: ANL 2016
[a] The values are calculated using AR4 global warming potential factors.
g CO_2e/MJ = grams of carbon dioxide equivalent per megajoule; CO_2e = carbon dioxide equivalent

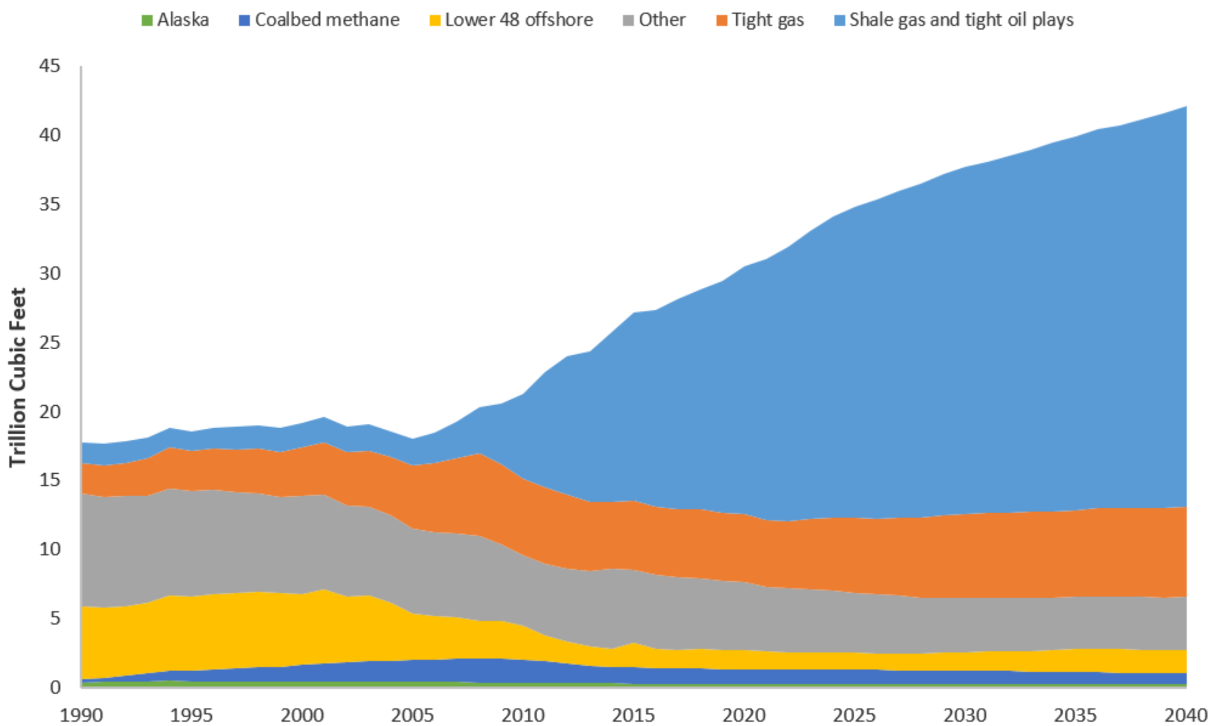
6.2.2 Natural Gas

Natural gas can be used in vehicles in compressed or liquid forms. In 2016, natural gas represented 0.1 percent of the total fuel supplied for passenger cars and light trucks. This share is projected to grow slightly in coming decades, to 0.2 percent by 2040 (EIA 2016c).[5] Increased market penetration of natural gas in the industrial, power, and transportation sectors is a result of increased United States production of natural gas, in large part due to development of shale gas resources, as shown in Figure 6.2.2-1. Production growth and improvements in shale gas extraction technologies have lowered natural gas prices, generating increased consumption in the previously mentioned sectors (EIA 2016c). During the

[5] Some compressed and liquefied natural gas used in vehicles is considered renewable natural gas (RNG), which is derived from biogas collected at landfills, municipal wastewater treatment facility digesters, agricultural digesters, and separated municipal solid waste digesters. Biogas from these sources is processed to be the same quality as pipeline-quality natural gas. EPA projects that 221 million gallons (approximately 0.0183 trillion cubic feet) of compressed natural gas or liquefied natural gas derived from renewable natural gas will be produced in 2018 (EIA 2017h). Because this accounts for a very small share of total U.S. natural gas production, renewable natural gas is not explored in detail as part of this chapter.

vehicle use phase, natural gas results in lower GHG emissions per unit of energy than other fossil fuels (EIA 2014a, 2014b). When substituted for coal to produce heat or electricity, natural gas has lower emissions of sulfur dioxide (SO_2), NO_X, and mercury (Hg) (Moore et al. 2014).

Figure 6.2.2-1. U.S. Natural Gas Production by Source, Annual Energy Outlook 2016 Reference Case



Source: EIA 2016c

Natural gas has recently become a significantly larger portion of U.S. electricity generation and is projected to increase in generation capacity over the coming decades. Electric vehicle sales could increase in the future compared to current levels (Chapter 8, *Cumulative Impacts*). Based on this, the life-cycle impacts of natural gas production and consumption are considered here.

6.2.2.1 Methane Emissions from Oil and Natural Gas

Methane accounted for an estimated 10 percent of total U.S. GHG emissions in 2015 (EPA 2017k). From 1990 through 2012, annual methane emissions decreased by 11 percent, largely because of emissions reductions from an EPA rule regulating landfills (EPA 2016a). However, in the United States, annual total methane emissions are projected to increase to approximately 8,570 million metric tons CO_2e ($MMTCO_2e$) by 2030, which would be a 26 percent increase in annual emissions compared to 2005 (EPA 2012f). Approximately 25 percent of the methane emitted in the United States is attributed to natural gas systems, and 6 percent comes from petroleum systems. Natural gas systems are currently the largest source of anthropogenic methane emissions in the U.S. (EPA 2017k). Because methane emissions from oil and natural gas are often presented together in the literature, this section includes a discussion of both natural gas and petroleum systems. Additional information on the life-cycle impacts of oil-based fuels is presented in Section 6.2.1, *Diesel and Gasoline*.

Methane emissions occur at multiple points upstream of the end use of oil and natural gas for industrial, power generation, and transportation purposes. Natural gas systems consist of four major stages:

production (extracting the natural gas), processing, transmission and storage, and distribution. Oil supply chain methane emissions primarily emanate from production, with smaller amounts emanating from transportation and refining. Methane emissions, which represent a combination of venting and leakage, occur at a variety of points in these different supply chain stages. EPA estimates that in 2015, the United States emitted 162.4 $MMTCO_2e$ of methane from upstream natural gas systems and 39.9 $MMTCO_2e$ from upstream oil processes. For natural gas, 65.6 percent of methane emissions were from field production, 6.8 percent were from processing, 20.8 percent were from transmission and storage, and 6.8 percent were from distribution. For oil, field production is the primary source of emissions with 97.9 percent of total emissions and 2.1 percent from transportation and refining (EPA 2017k). These emissions do not include emissions related to use of natural gas (i.e., combustion of natural gas in vehicles). The primary sources of methane emissions are as follows:

- **Production (natural gas and oil)**. The most significant identified natural gas production sources of methane emissions identified in the EPA 2015 GHG Inventory[6] (referred to as the EPA inventory) are gathering stations, pneumatic controllers, kimray pumps, liquids unloading, condensate tanks, gathering pipeline leaks, and offshore platforms (EPA 2016a). Sources of emissions in oil production include pneumatic controllers, offshore oil platforms, gas venting and flaring, engines, chemical injection pumps, oil tanks, hydraulically fractured well completions, and oil wellheads (EPA 2017k).
- **Processing (natural gas).** Raw natural gas is composed of methane as well as other impurities. To prevent pipeline corrosion, these impurities must be removed before the natural gas can be transported and serve its end-use purpose. At processing facilities, the natural gas is separated from the other constituents of the raw gas. This requires maintaining certain levels of pressure during processing, and during the processing stage methane emissions arise mainly from compressors (EPA 2016a).
- **Transmission and storage (natural gas).** This processed natural 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. During transmission, methane emissions mainly arise from the compressor stations and pneumatic controllers. Natural gas is stored during periods of low demand and distributed during periods of high demand. When natural gas is stored, it can leak from compressors and dehydrators.
- **Distribution (natural gas).** During distribution, natural gas is emitted mainly from the gate stations and pipelines.

A reduction in leaks and venting throughout upstream natural gas life-cycle stages has resulted in a 16 percent decrease in overall natural gas methane emissions from 1990 to 2015. Field production of oil methane emissions has also decreased; emissions declined by 29 percent between 1990 and 2015 due to decreases in vented methane (EPA 2017k).

There has been a wealth of research and literature around quantifying methane emissions and understanding how to reduce emissions. Previous studies find that methane emissions can occur in multiple locations upstream and 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). More recent studies that use on-site measurements for specific regions have analyzed upstream

[6] Annually, EPA compiles the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* report, referred to here as the GHG Inventory. The Inventory estimates national GHG emissions and removals by source, economic sector, and GHG type. The latest report includes data for each year from 1990 to 2015 (EPA 2017k).

methane emissions from natural gas and oil production and processing (Marchese et al. 2015, Zavala-Araiza et al. 2015a, Lyon et al. 2015) to storage and distribution (Zimmerle et al. 2015, Lamb et al. 2015). These studies reveal that emissions can vary significantly throughout natural gas and oil systems, but additional on-site measurements—particularly of super-emitters that constitute a major share of total industry emissions—are needed to better quantify overall emissions and enhance mitigation. The EPA inventory has been significantly updated in light of these studies. Using Intergovernmental Panel on Climate Change (IPCC) and EPA resources on oil and gas densities, and EIA data for U.S. production, the EPA GHG Inventory leak rate in 2015 for oil and gas systems was about 1 percent of total production (EPA 2016a, IPCC 2006, EIA 2018b, EIA 2018c, EPA 1995b).

Methane leak rates upstream of oil and gas consumption play a critical role in LCAs of fuel pathways. Multiple studies modeled the effects of various leak rates on life-cycle GHG emissions of natural gas for electricity generation. An LCA assessing natural gas pathways for use in alternative light-duty fuel vehicles found that, on a life-cycle basis, natural gas vehicles became less fuel efficient than conventional gasoline vehicles at given upstream methane leak rates (1 to 11 percent) depending on the vehicle and fuel type (Tong et al. 2015). A similar study modeled the effects of various methane leak rates of less than 5 percent in natural gas systems, finding that increasing a leak rate from 1 to 5 percent increases overall life-cycle emissions of natural gas from 0.16 to 0.81 g CO_2e/MJ (Farquharson et al. 2016). While the current EPA inventory estimate for overall leak rates is on the lower end of these variations, a few specific sites in natural gas systems can exceed 4.6 percent, with these super-emitter sites responsible for a majority of methane emissions (Zavala-Araiza et al. 2015b). However, a recent study estimated that the 2015 EPA inventory is underreporting supply chain methane emissions from oil and natural gas industries by about 60 percent. The authors found that this underreporting is due to current EPA inventory estimation methods not capturing methane emissions from abnormal operating conditions in production (Alvarez et al. 2018).

6.2.2.2 Shale Gas and Hydraulic Fracturing

Hydraulic fracturing of shale gas deposits has traditionally been referred to as an unconventional source of natural gas but has become the largest source of natural gas in the United States in the last decade. In 2015, hydraulically fractured wells accounted for 67 percent of marketed U.S. natural gas production (EIA 2016d).

Shale gas is sourced from gas-rich, low-permeability shale formations that consist of hydrocarbons trapped in fractures and pores of rock deep underground. To access and extract this gas, a well is drilled down to the shale formation and then turned horizontally to follow the shale formation. Gas is then freed by forcing a mixture of water, sand, and chemicals at high pressure to fracture the shale formation and force the gas to the wellhead (NETL 2011). These techniques result in upstream environmental impacts that differ from those of conventional natural gas extraction. This section focuses on two significant environmental concerns surrounding shale gas development: GHG and other air pollutant emissions, and water-related impacts (i.e., water pollution and consumption).

Following the rapid rise of shale gas development and consumption, shale gas became a trending topic in LCA research, primarily focused on life-cycle GHG emissions. Two LCA shale gas literature reviews compare and assess the results of almost 20 different LCAs. Weber and Clavin (2012) analyzed the sensitivity of emissions from hydraulic fracturing natural gas production to different study assumptions. Heath et al. (2014) used a harmonization approach as part of the broader National Renewable Energy Laboratory’s electricity LCA harmonization research. This harmonization approach adjusts the models of existing LCAs to create comparable boundaries and assumptions (e.g., including emissions from liquids unloading, consistent global warming potential factors) for a more consistent comparison of results (Heath et al. 2014).

Upstream of electricity generation or other fuel combustion, production and supply of shale gas has several variables that drive LCA emissions estimates. Regional variations in the characteristics of shale formations and wells affect the estimated ultimate recovery of methane (Weber and Clavin 2012). Methane leaked, vented, or flared varies between studies. Methane emissions from shale gas development, production, and supply are detailed in Section 6.2.2.1, *Methane Emissions from Oil and Natural Gas.* Table 6.2.2-1 summarizes the results from upstream GHG emission for both shale and conventional gas from these LCA reviews. For the median case in each study, upstream natural gas GHG emissions represent 13 to 20 percent of shale gas life-cycle emissions, and 14 to 16 percent of conventional natural gas life-cycle emissions.[7] Note that the low and high results for Heath et al. (2014) reflect the 25th and 75th percentiles and maximum and minimum values for Weber and Clavin (2012). A more recent LCA of shale gas produced from the Marcellus shale formation found upstream GHG emissions to be 28 g CO_2e/MJ, or about 20 percent of total life-cycle emissions, similar to the results of Heath et al. (2014) (Laurenzi 2015).

Table 6.2.2-1. Results Summary for Upstream Shale Gas LCA Literature Reviews

LCA Literature Review	Shale Gas (g CO_2e/MJ Generated)			Conventional Gas (g CO_2e/MJ Generated)		
	Low	Median	High	Low	Median	High
Heath et al. (2014)	18	25	39	11	19	22
Weber and Clavin (2012)	8	15	27	5	16	18

LCA = life-cycle assessment; g CO2e/MJ = grams of carbon dioxide equivalent per megajoule

Upstream shale gas production activities have also created concerns for increased air pollution emissions from drilling and fracturing operations and trucking (Zoback and Arent 2014). One study estimated Pennsylvania air pollution emissions (volatile organic compounds, NO_X, SO_X, and particulate matter greater than 2.5 or 10 microns in diameter (PM2.5 and PM10, respectively)) using 2011 data from transportation activities (water, equipment, and wastewater), well drilling and hydraulic fracturing (fuel use), natural gas production (fuel use and methane leaks), and compressor stations (fuel use). Drilling, fracturing, and production activities accounted for the majority of emissions, with transportation contributing less than 10 percent across all pollutants (Litovitz et al. 2013).

Hydraulic fracturing water pollution concerns center on wastewater handling and local groundwater vulnerabilities. Wastewater primarily comes from flowback, the fluid used in hydraulic fracturing that returns to the surface during and after operations, which can contain contaminants (e.g., salt, selenium, arsenic, iron). Efforts to reduce wastewater treatment needs include flowback reuse, where some operations reuse nearly all flowback for future wells, returning contaminants to the original formations (Zoback and Arent 2014). Flowback reuse also alleviates freshwater use in fracturing operations. While freshwater consumption estimates in the literature have significant uncertainties, one literature review estimates freshwater consumption in shale gas extraction to be more than twice as high as in

[7] Life-cycle emission calculations assume natural gas will be combusted for electricity generation.

conventional gas extraction (Cooper et al. 2016). Other industry practices in minimizing freshwater consumption include using brackish or saline water for fracturing (Zoback and Arent 2014). Local groundwater contamination impacts can come from well construction or drilling practices. Close attention in casing and cement design and construction and pressure management can prevent contamination risks (Zoback and Arent 2014).

There is also evidence that hydraulic fracturing can induce seismic events, where an increase in earthquakes is clustered around hydraulic fracturing sites. This evidence has been limited to a study in Western Canada, where injection occurs in shale formations with highly impermeable layers (Bao and Eaton 2016). Induced seismic events in the United States, namely in the Midwest, have been linked to wastewater and saltwater disposal wells into permeable layers (Bao and Eaton 2016, USGS 2017). A USGS analysis revealed that earthquakes east of the Rocky Mountains, primarily in Oklahoma, have increased substantially since 2009. This timeline coincides with the rise of shale oil and gas production in the region, which generates increased volumes of wastewater injection into geologic formations. Before 2009, Oklahoma experienced low-magnitude (a rating of three to four on the momentum magnitude scale) earthquakes once or twice annually. Since 2014, these low- magnitude events have been occurring daily, with limited instances of higher-magnitude events (ratings of five to six) (EIA 2017i).

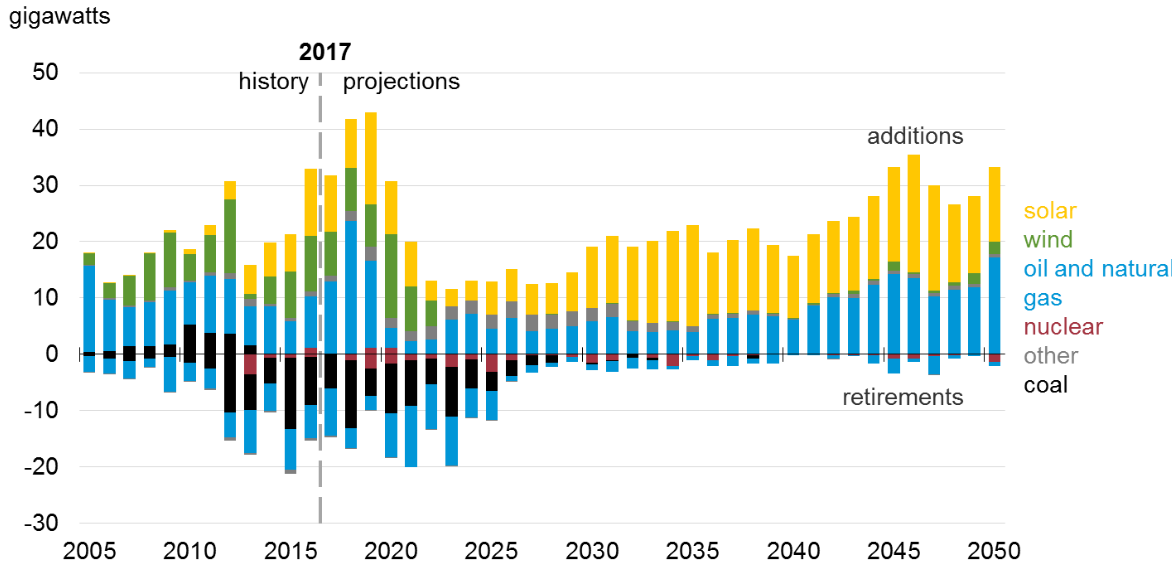
6.2.3 Electric Vehicles

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 BEVs, HEVs, and PHEVs (Notter et al. 2010, Patterson et al. 2011, DOE 2013a). HEVs incorporate a battery and electric motor combined with an internal combustion engine (or fuel cell), and have onboard charging capabilities (e.g., regenerative braking) but are not charged by the electric grid. 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. BEVs are purely electrically powered and do not incorporate an internal combustion engine. For more information on EVs and market trends, see Chapter 8, *Cumulative Impacts*.

EV LCAs have centered on three primary life-cycle phases in quantifying environmental impacts: vehicle manufacturing, battery manufacturing, and vehicle operations. Air quality and climate impacts reported in Chapters 4 and 5 do not include vehicle or battery manufacturing LCA impacts but do reflect downstream (tailpipe) and upstream (refinery and electricity generation) emissions associated with fuel used in vehicle operations. Upstream emissions reflected in Chapter 4, *Air Quality,* and Chapter 5, *Greenhouse Gas Emissions and Climate Change*, are based on recent forecasts for the mix of fuels used for U.S. electricity generation, consistent with the AEO 2018 forecast. This U.S. grid mix has changed significantly over the past decade, and this means that older LCAs based on different grid mix assumptions might not be comparable with findings in Chapters 4 and 5, which are based on more recent grid mix forecasts. Some LCAs of EVs and internal combustion vehicles have also examined the impacts from end-of-life management of vehicle batteries, as summarized in Section 6.3.3, *Vehicle Batteries*.

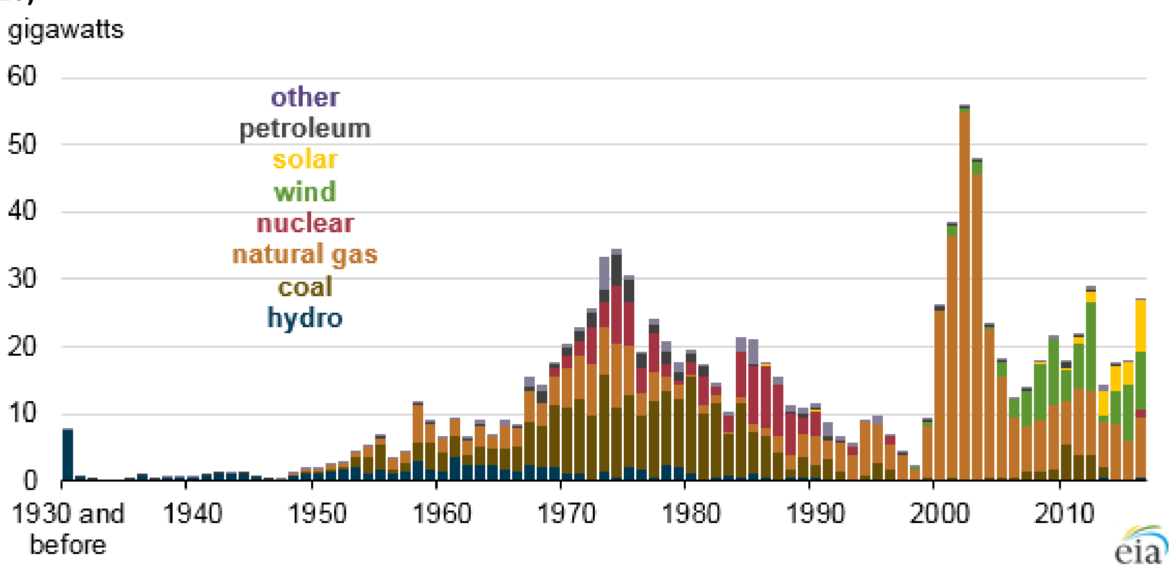
Figure 6.2.3-1 shows that oil, natural gas, wind, and solar power accounted for most electricity capacity additions from 2005 through 2017, and coal power plants accounted for most power plant retirements. Figure 6.2.3-2 shows that natural gas power plants also accounted for most of the capacity additions in the 1990s. This projected increase in natural gas and renewable energy sources in the electricity grid mix will lower the GHG emissions associated with electricity consumption, and subsequently BEV use, over time.

Figure 6.2.3-1. Historical and Projected U.S. Utility-Scale Electric Capacity Additions and Retirements (2005 to 2050)



Source: EIA 2018a

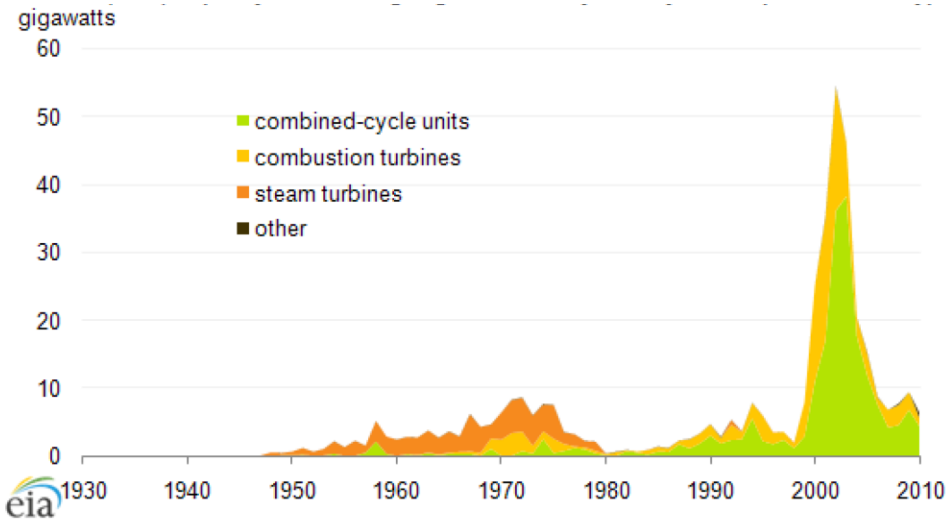
Figure 6.2.3-2. U.S. Utility-Scale Electric Generating Capacity by Initial Operating Year (as of December 2016)



Source: EIA 2017j

The increase in natural gas power plant capacity since the 1980s is primarily from the addition of combined-cycle units, as shown in Figure 6.2.3-3. Combined-cycle plants are much more efficient than other types of power plants, where efficiency is measured by power plant heat rate, which is the number of British thermal units (Btu) from source fuel needed to generate 1 kilowatt-hour (a lower heat rate indicates more efficient source fuel conversion). The average heat rate for combined-cycle natural gas plants is approximately 7,500 Btu per kilowatt-hour, compared to average heat rates above 10,000 Btu per kilowatt-hour for coal power plants and older natural gas combustion turbine and steam turbine plants (EIA 2017l).

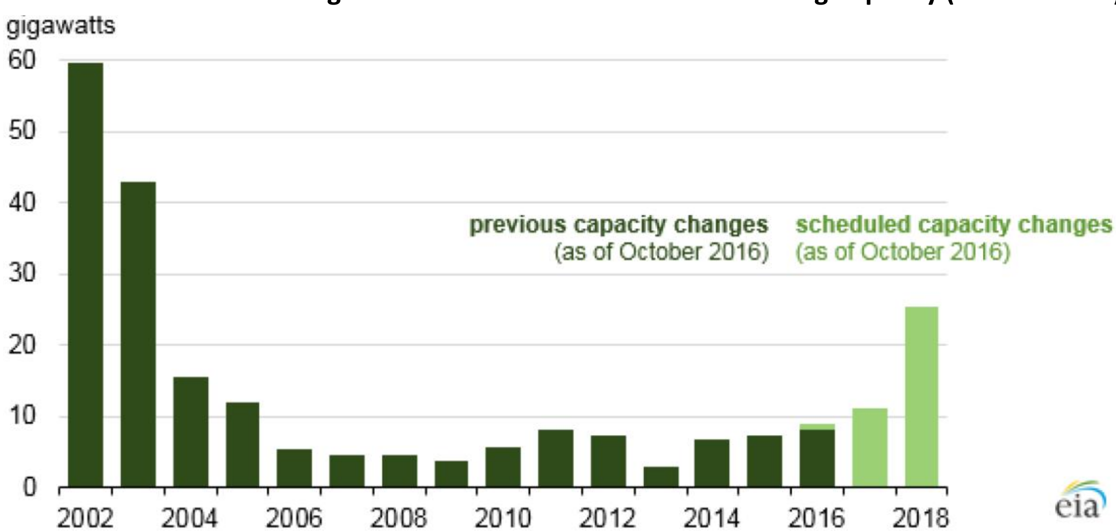
Figure 6.2.3-3. 2010 Capacity of Natural Gas Generators, by Initial Year of Operation and Type



Source: EIA 2011c

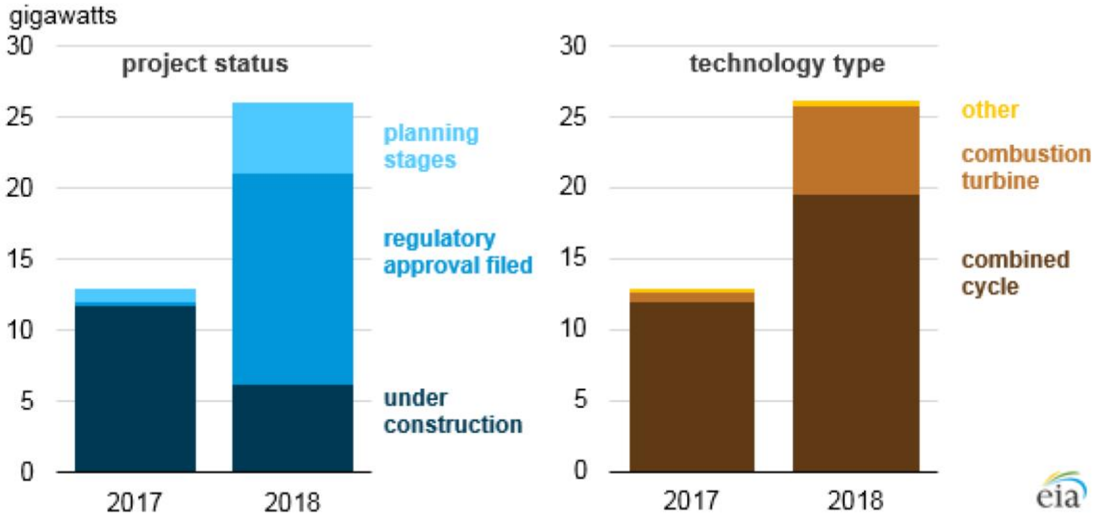
As new combined-cycle plants have been added, and less-efficient natural gas combustion and steam turbine plants are retired, the overall average heat rate for natural gas power plants has declined from approximately 8,100 in 2006 to 7,800 in 2015 (EIA 2017l). EIA also reports substantial scheduled natural gas capacity additions in 2017 and 2018, with combined-cycle power plants accounting for most of this increase in generating capacity, as shown in Figures 6.2.3-4 and 6.2.3-5.

Figure 6.2.3-4. Net Annual Change in U.S. Natural Gas Electric Generating Capacity (2002 to 2018)



Source: EIA 2017k

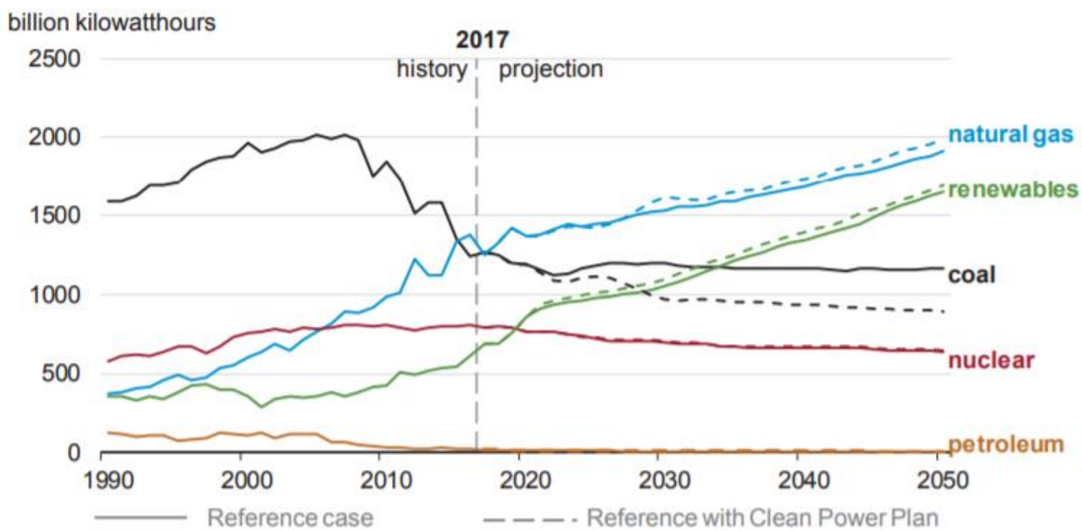
Figure 6.2.3-5. 2010 Capacity of Natural Gas Generators, by Initial Year of Operation and Type



Source: EIA 2017k

Figure 6.2.3-6 shows that coal U.S. electricity generation fell from approximately 2,000 billion kilowatt-hours (kWh) in 2010 to 1,250 billion kWh in 2017, reflecting the combined impact of additional natural gas and renewable energy generating capacity and historically low natural gas prices. AEO 2018 projects that generation will remain near this level out to 2050, but could fall below 1,000 billion kWh by 2050 if the Clean Power Plan is implemented (EIA 2018a).

Figure 6.2.3-6. Net Electricity Generation by Source (1990 to 2050)



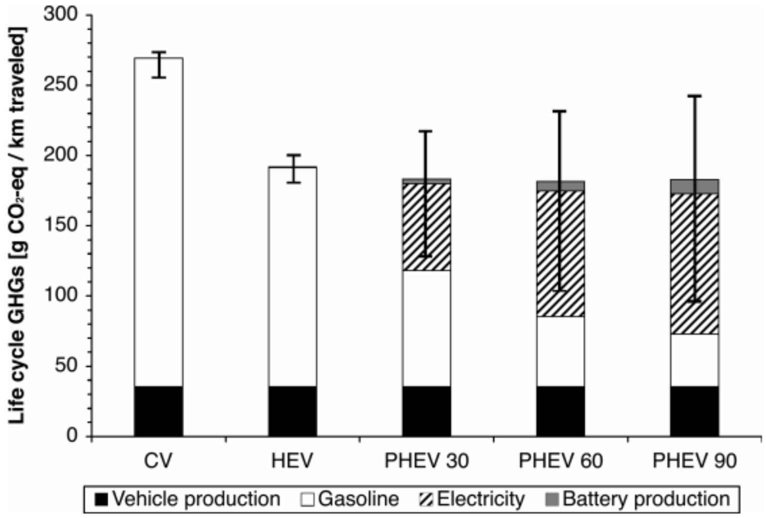
Source: EIA 2018a

Figure 6.2.3-7 shows the relative contributions of these phases to life-cycle EV GHG emissions, including variations for electricity grid mixes, from an LCA published by Samaras and Meisterling (2008).[8] The operation phase (more specifically, electricity consumption during operation) accounts for a significant

[8] Although Figure 6.2.3-7 is focused on HEVs and PHEVs, the operation phase findings extend to BEVs based on conclusions from more recent studies including Hawkins et al. (2012) and Nealer and Hendrickson (2015).

portion of a vehicle's life-cycle environmental impacts (Samaras and Meisterling 2008, Gaines et al. 2011, Notter et al. 2010).

Figure 6.2.3-7. Life-Cycle Greenhouse Gas Emissions of U.S. Electric Vehicles



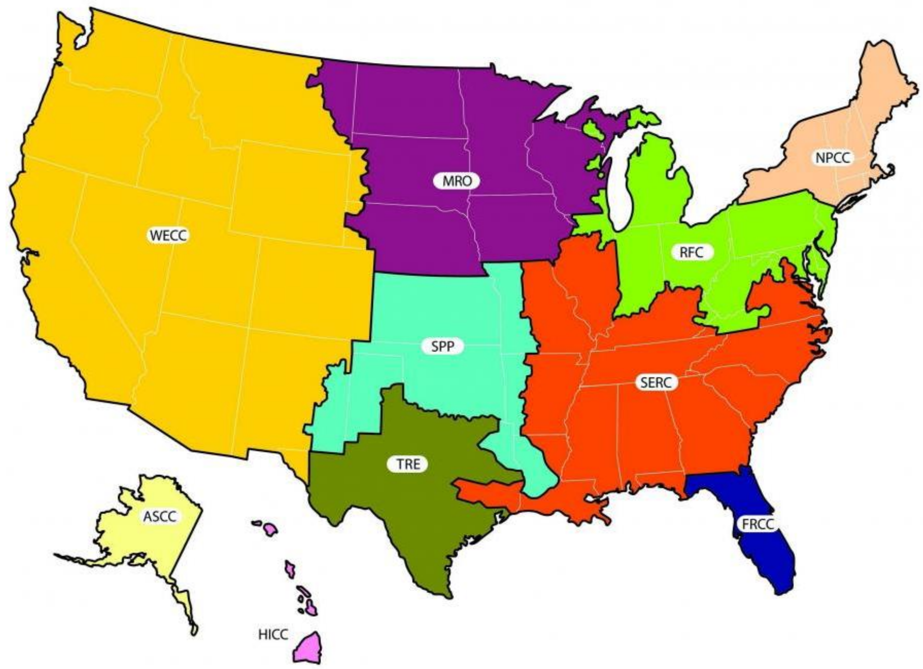
Source: Samaras and Meisterling 2008
CO_2-eq = carbon dioxide equivalent; CV = conventional vehicle; HEV = hybrid electric vehicle; PHEV 30/60/90 = plug-in hybrid electric vehicle with all-electric ranges of 30, 60, or 90 km, respectively. Life cycle GHG intensity of electricity represents a U.S. average value of 670 g CO_2e/kWh; uncertainty bars represent changes in total emissions under the carbon-intensive electricity scenario (950 g CO_2e/kWh) or low-carbon electricity scenario (200 g CO_2e/kWh).

This section focuses on EV operations (i.e., use phase) and the associated life-cycle environmental impacts. This primarily consists of examining the dynamics of EV electricity consumption, including location and time of consumption. Electricity generation sources are the drivers of EV operation impacts. However, material production impacts are important considerations in EV LCAs, as EVs use more rare earth elements in drivetrain and battery design than internal combustion vehicles, which increase overall environmental impacts outside of vehicle operations (Gradin et al. 2017). Associated impacts of EV material production and end-of-life management are examined in Section 6.3.3, *Lithium-Ion Vehicle Batteries*.

6.2.3.1 Charging Location

The LCA literature concludes that use-phase GHG emissions from EVs depend on several factors, including *where* they are charged (Elgowainy et al. 2010, Holland et al. 2015, Nealer and Hendrickson 2015, Onat et al. 2015, Tamayao et al. 2015). This is primarily because the grid mix used to supply electricity to EVs varies by location. In the United States, the grid mix consists of coal, natural gas, nuclear, hydroelectric, oil, and renewable energy sources. The relative proportions of these components can be analyzed by regions, including National Electricity Reliability Commission (NERC) regions (Figure 6.2.3-8) and EPA Emissions & Generation Resource Integrated Database (eGRID) subregions, which are based on energy transmission, distribution, and utility territories to analyze the environmental aspects of power generation (Figure 6.2.3-9) (Tamayao et al. 2015). For example, in the eGRID subregion that includes Missouri and much of Illinois, 74 percent of electricity is generated by coal, while in most of Alaska, 78 percent of energy comes from hydropower, indicating that the magnitude of emissions associated with EVs charged in the two subregions would likely differ significantly. A breakdown of grid mix by eGRID subregion is shown in Figure 6.2.3-10.

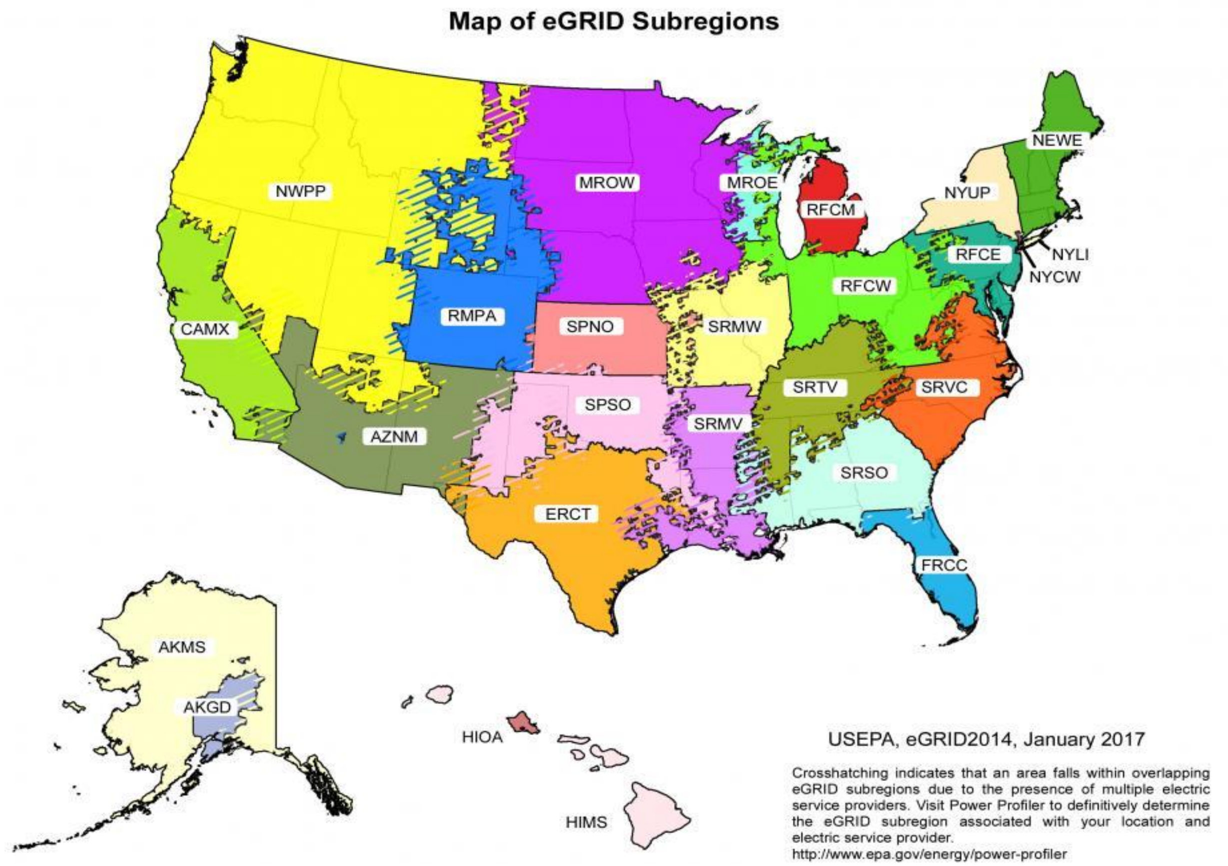
Figure 6.2.3-8. National Electricity Reliability Commission Regional Map



Source: EPA 2015e

FRCC = Florida Reliability Coordinating Council; MRO = Midwest Reliability Organization; NPCC = Northeast power Coordinating Council; RFC = Reliability First Corporation; SERC = SERC Reliability Corporation; SPP= Southwest Power Pool; TRE = Texas Reliability Entity; WECC = Western Electricity Coordinating Council; ASCC = Alaska Grid; HICC = Hawaii

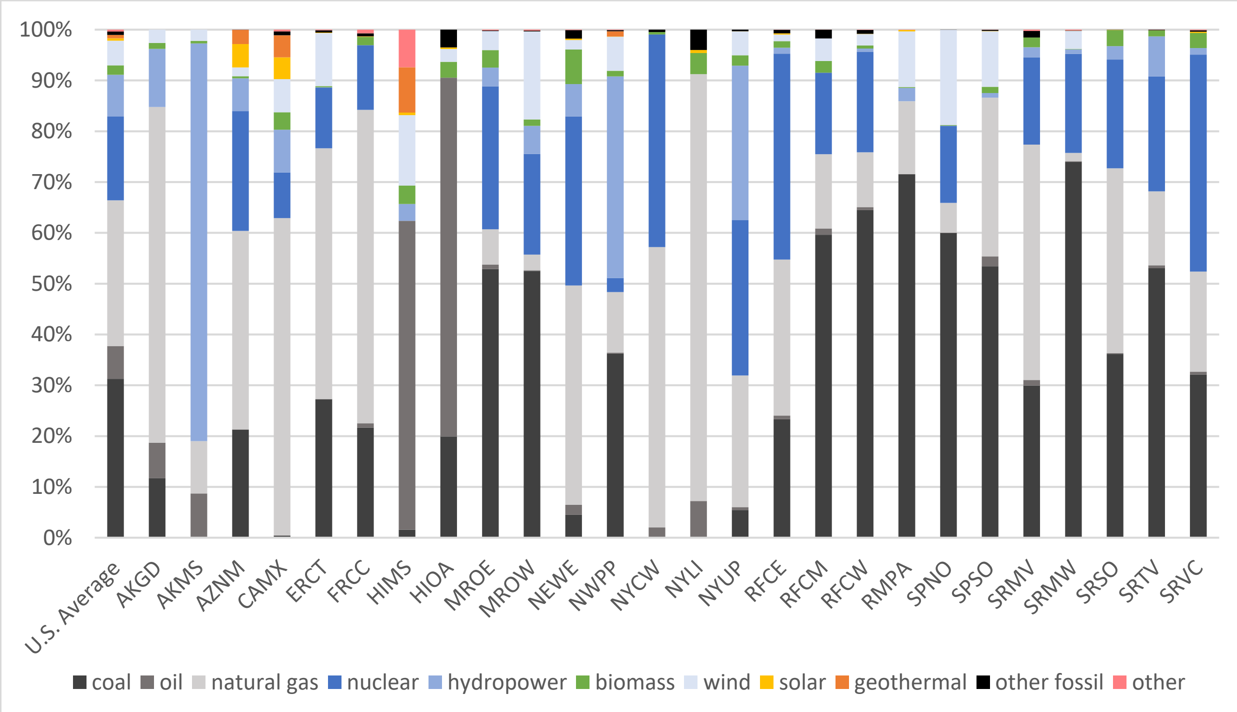
Figure 6.2.3-9. Environmental Protection Agency eGRID Subregions



Source: EPA 2017a

eGRID = Emissions & Generation Resource Integrated Database. eGRID subregions are derived from NERC names: FRCC = FRCC All; MORE = MRO East; MROW = MRO West; NEWE = NPCC New England; NYCW = NPCC NYC/Westchester; NYLI = NPSS long island; NYUP = NPCC Upstate NY; RFCE = RFC East; RFCM = RFC Michigan; RFCW = RFC West; SRMW = SERC Midwest; SRMV = SERC Mississippi Valley; SRSO = ERV South, SRTV = SERC Tennessee Valley; SRVC = SERC Virginia/Carolina; SPNO = SPP North; SPSO = SPP South; CAMX = WECC California; NWPP = WECC Northwest; RMPA = WECC Rockies; AZNM = WECC Southwest; ERCT = Electric Reliability Council of Texas; AKGD = ASCC Alaska Grid; AKMS = ASCC Miscellaneous; HIOA = HICC Oahu; HIMS = HICC Miscellaneous

Figure 6.2.3-10. 2014 U.S. Average and eGRID Subregion Grid Mix

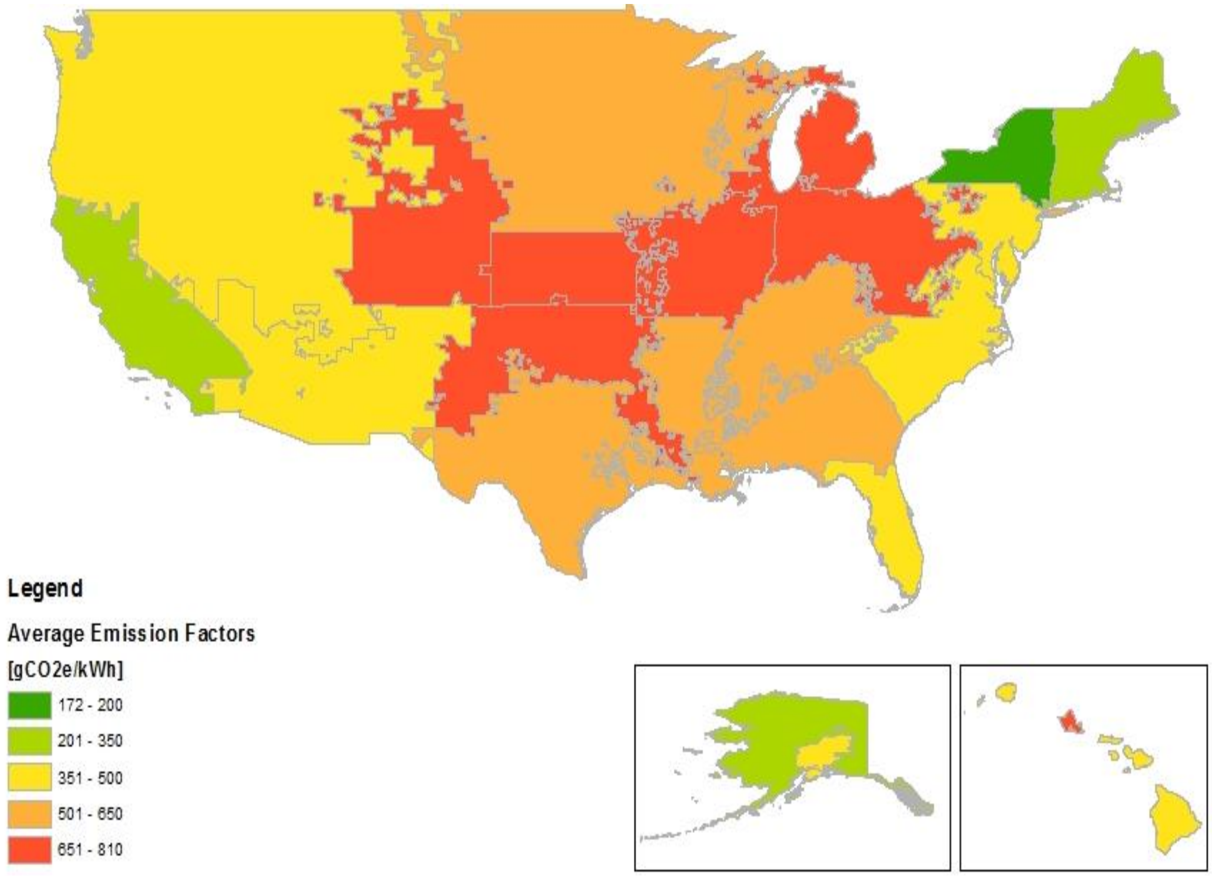


Source: EPA 2017c

eGRID = Emissions & Generation Resource Integrated Database. Regional names are derived from NERC regional names: FRCC = FRCC All; MORE = MRO East; MROW = MRO West; NEWE = NPCC New England; NYCW = NPCC NYC/Westchester; NYLI = NPSS long island; NYUP = NPCC Upstate NY; RFCE = RFC East; RFCM = RFC Michigan; RFCW = RFC West; SRMW = SERC Midwest; SRMV = SERC Mississippi Valley; SRSO = ERV South, SRTV = SERC Tennessee Valley; SRVC = SERC Virginia/Carolina; SPNO = SPP North; SPSO = SPP South; CAMX = WECC California; NWPP = WECC Northwest; RMPA = WECC Rockies; AZNM = WECC Southwest; ERCT = Electric Reliability Council of Texas; AKGD = ASCC Alaska Grid; AKMS = ASCC Miscellaneous; HIOA = HICC Oahu; HIMS = HICC Miscellaneous

Because of the variation in grid mixes, electricity average emission factors (AEFs) vary significantly by subregion, with the most carbon-intensive subregion of the United States emitting more than 4.7 times as much CO_2 per kilowatt-hour relative to the least carbon-intensive subregion, as shown in Figure 6.2.3-11. Generally, AEFs (and emissions associated with EV use-phase electricity consumption) are lowest in the West, Northeast, and Alaska, and highest in the middle of the country.

Figure 6.2.3-11. eGRID Subregion Average Emission Factors for Electricity (g CO_2e/kWh).

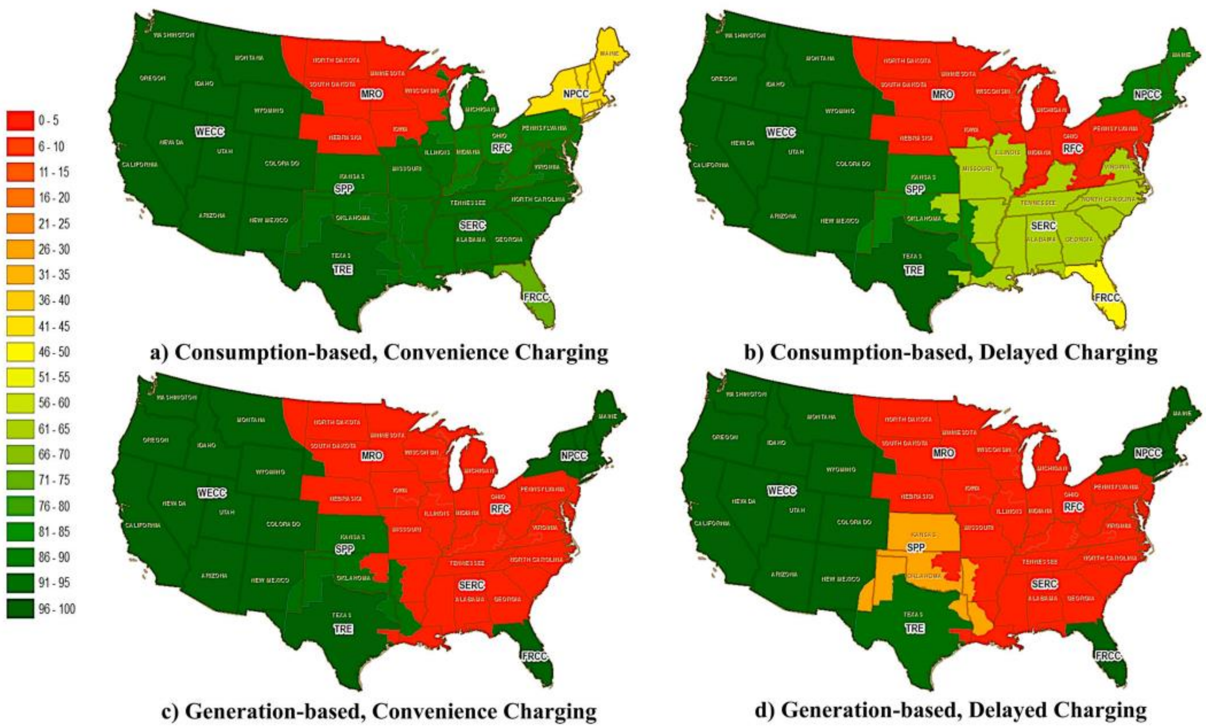


Source: EPA 2017c
eGRID = Emissions & Generation Resource Integrated Database; g CO_2e/kWh = grams of carbon dioxide equivalent per kilowatt –hour; g CO_2e/kWh = grams of carbon dioxide equivalent per kilowatt-hour

A National Renewable Energy Laboratory (NREL) BEV use-phase study (McLaren et al. 2016) estimated GHG emissions per day for potential BEV and PHEVs, and found that total daily emissions for a BEV increased by more than a factor of three between a low carbon electricity mix (97 percent renewables and hydropower, 8.8 kg CO_2/day) and high carbon mix (93 percent coal, 26.4 kg CO_2/day).

Marginal electricity refers to electricity generated in response to a new load at a given time and location (Tamayao et al. 2015). The use of marginal emission factors (MEFs) rather than AEFs can significantly affect EV life-cycle impacts, as electricity consumption emission factors are highly variable and dictate use-phase emissions. Tamayao et al. (2015) characterized regionally specific life-cycle CO_2 emissions per mile traveled for BEVs, HEVs, and internal combustion engine vehicles by NERC region under alternative assumptions for regional electricity emission factors and charging schemes. The authors presented their findings by listing the median CO_2 emissions difference between a BEV and a HEV and between a BEV and an internal combustion engine vehicle in a given NERC subregion. The authors accounted for two different electricity emission factor methods (consumption-based MEFs and generation-based MEFs) and two different charging schemes (convenience charging and delayed charging at off-peak hours). Consumption-based MEFs refer to electricity CO_2 emissions based on total electricity consumed, and generation-based uses total electricity generated (Zivin et al. 2014). Tamayao et al. (2015) found that BEVs produced the lowest emissions relative to HEVs and internal combustion engine vehicles in western regions and in Texas. Results indicate that the MEF method chosen and the charging scheme can have a significant impact on BEV emissions (Figure 6.2.3-12).

Figure 6.2.3-12. Probability that a BEV Emits CO_2 at a Lower Rate than a HEV or Internal Combustion Engine Vehicle



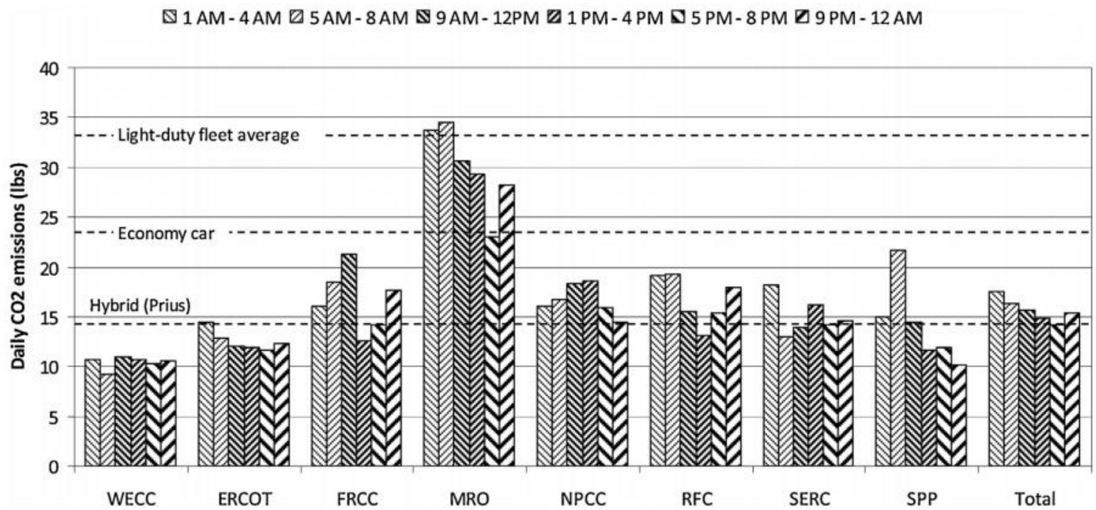
Source: Tamayao et al. 2015

Green indicates that the BEV is lower emitting than the gasoline vehicle (HEV or sales-weighted internal combustion engine vehicle), while red means the opposite.

FRCC = Florida Reliability Coordinating Council; MRO = Midwest Reliability Organization; NPCC = Northeast power Coordinating Council; RFC = Reliability First Corporation; SERC = SERC Reliability Corporation; SPP= Southwest Power Pool; TRE = Texas Reliability Entity; WECC = Western Electricity Coordinating Council; ASCC = Alaska Grid; HICC = Hawaii

Zivin et al. (2014) analyzed spatial variation in average and marginal emissions and found that average emission rates are nearly twice as much in the upper Midwest relative to the western United States (1.63 versus 0.83 pounds CO_2 per kilowatt-hour). Marginal emission rates are nearly three times greater in the upper Midwest relative to the western United States (2.30 versus 0.80 pounds CO_2 per kilowatt-hour). Marginal emission rates are further discussed in Section 6.2.3.2, *Marginal Grid Greenhouse Gas Intensity.* Using marginal emissions to estimate CO_2 emissions per mile, Zivin et al. (2014) found that emissions are lower for EVs than from HEVs in the western United States (WECC) and Texas (ERCOT), while the opposite is true in the upper Midwest (MRO), as shown in Figure 6.2.3-13 (Zivin et al. 2014). Under this study, the upper Midwest MRO region is also the only region where the average internal combustion engine economy car is less GHG-intensive than an EV.

Figure 6.2.3-13. Daily Battery Electric Vehicle Carbon Dioxide Emissions by National Electricity Reliability Commission Region and Time of Day, Assuming 35 Miles Driven per Day[a]



Source: Zivin et al. 2014

[a] The dashed horizontal lines illustrate emissions from internal combustion engines, including the average light-duty vehicle and economy car, and from the Prius hybrid electric vehicle.

CO_2 = carbon dioxide; NERC = National Electricity Reliability Commission; WECC = Western Electricity Coordinating; ERCOT = Electric Reliability Council of Texas; FRCC = Florida Reliability Coordinating Council; MRO = Midwest Reliability Organization; NPCC = Northeast power Coordinating Council; RFC = Reliability First Corporation; SERC = SERC Reliability Corporation; SPP= Southwest Power Pool

Electricity grid mix also plays a substantial role in EV life-cycle air pollution outside of GHG emissions. EV electricity consumption is a main driver of life-cycle particulate matter, SO_X, and NO_X emissions, as well as ozone formation (Weis et al. 2016, Tessum et al. 2014, Hawkins et al. 2013). Carbon-intensive grid mixes, primarily those that are reliant on coal, create significantly higher particulate emissions and ozone formation potential than conventional internal combustion engine vehicles (Hawkins et al. 2013, Tessum et al. 2014). Substituting coal electricity generation with renewable or less carbon-intensive sources can reduce EV life-cycle particulate matter, NO_X, and SO_X emissions substantially (Weis et al. 2016).

In summary, the studies cited in Section 6.2.3.1 find that EVs use-phase emissions are lowest for EVs charged in the West, Northeast, and Texas, a pattern that is consistent with grid mix and associated emission factors. The literature indicates that in current grid mixes, EVs emit less than internal combustion engine vehicles throughout most, if not all, of the United States; the upper Midwest (the MRO NERC region) is the only region where this is consistently shown to not hold true based on the studies reviewed.[9] In comparing EV and HEV emissions, EVs emit less than HEVs in the West and Texas (the WECC and TRE/ERCOT NERC regions) and emit more in the upper Midwest (the MRO region). The results are mixed, varying based on emission factor estimation method and charging time, in the Northeast, the Southeast, and Central United States (the NPCC, FRCC, SPP, SERC, and RFC regions). Reducing grid mix carbon intensity reduces both GHG and criteria pollutant emissions for the EV use phase.

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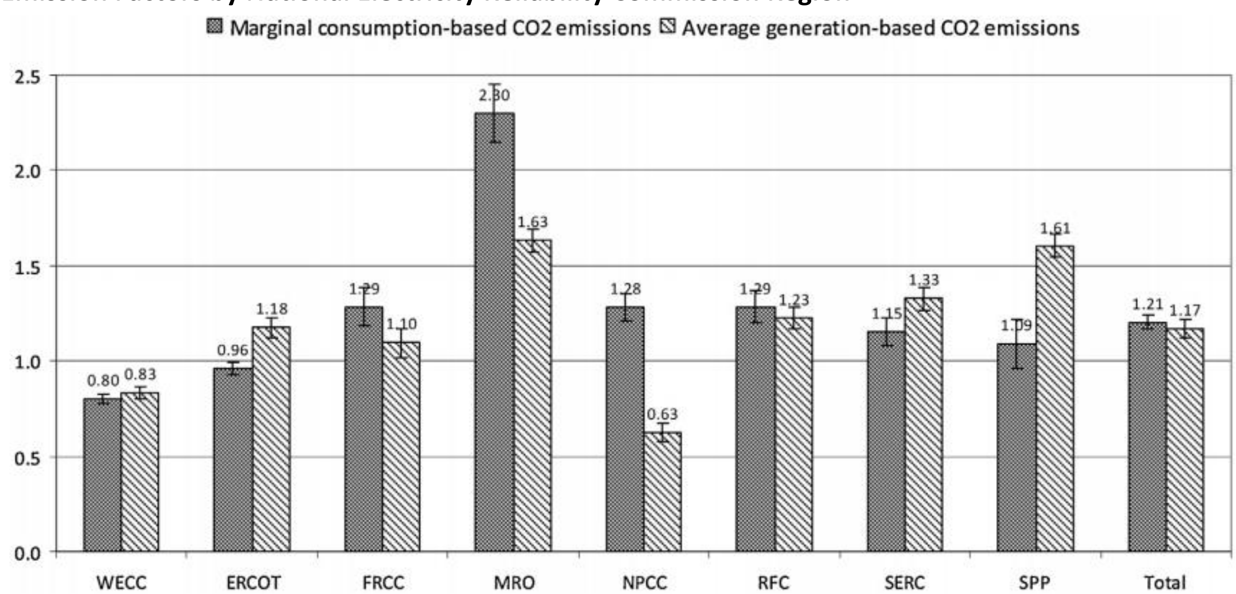
[9] Future electricity grid mixes could change and potentially raise the GHG intensity of regional grid mixes, which could affect this conclusion.

6.2.3.2 Marginal Grid Greenhouse Gas Intensity

MEFs discussed in Section 6.2.3.1 focus on specific locations relative to the national average, but several studies have focused on emission variations from the timing of electricity consumption and EV charging. Both time of day (peak vs. off-peak loads) and seasonal fluctuations can affect the GHG intensity of electricity generation (Archsmith et al. 2015). Some studies argue that MEFs more accurately reflect the emissions associated with the electricity used to fuel EVs (Nealer and Hendrickson 2015, Ryan et al. 2016). However, the high variation in MEFs creates difficulty in determining which power plant responds to meet marginal electricity demand (Tamayao et al. 2015). Therefore, many studies use AEFs to calculate EV emissions (Nealer and Hendrickson 2015, Tamayao et al. 2015). The difference between the two types of emission factors can translate to a discrepancy of up to 50 percent for a given NERC region and 120 percent for a given state for estimates of GHG emissions per vehicle mile traveled (Tamayao et al. 2015). Some studies take an alternate approach, generating hypothetical scenarios for electricity emissions outside of MEFs or AEFs, but these studies are subjective and may not reflect real-world behavior (Weis et al. 2016).

The regional discrepancy between MEFs and AEFs is illustrated in Figure 6.2.3-14 (Zivin et al. 2014). While MEFs differ significantly from AEFs in the Northeast (NPCC: 103 percent difference), upper Midwest (MRO: 40 percent difference), and central United States (SPP: -32 percent difference), differences are minimal in the West (WECC: 4 percent difference) and the Mid-Atlantic/Midwest (RFC: 5 percent difference). Gas is generally the largest marginal fuel source in regions where MEFs approximate or are lower than AEFs (e.g., marginal fuel is 81 percent gas in NPCC, 86 percent in WECC, 84 percent in TRE [ERCOT]). Coal or oil are significant marginal fuel sources where MEFs exceed AEFs (e.g., marginal fuel is 79 percent coal in MRO and 70 percent in RFC, and marginal fuel is 12 percent oil in FRCC and 11 percent in NPCC) (Siler-Evans et al. 2012).

Figure 6.2.3-14. Marginal Emission Factors and 95 Percent Confidence Intervals versus Average Emission Factors by National Electricity Reliability Commission Region

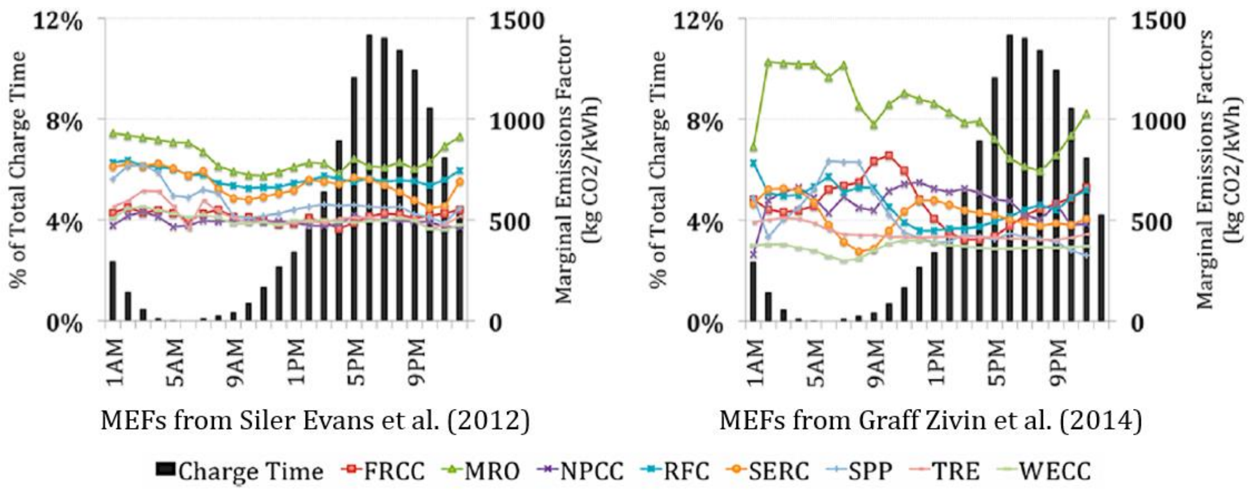


Source: Zivin et al. 2014

CO_2 = carbon dioxide; NERC = National Electricity Reliability Commission; FRCC = Florida Reliability Coordinating Council; MRO = Midwest Reliability Organization; NPCC = Northeast Power Coordinating Council; RFC = Reliability First Corporation; SERC = SERC Reliability Corporation; SPP= Southwest Power Pool; WECC = Western Electricity Coordinating Council

MEFs vary throughout the day (Figure 6.2.3-15). For many NERC regions, MEFs are lower than AEFs during the 7 to 8 a.m. electricity load peak, at which point natural gas is often used to fuel marginal electricity (Tamayao et al. 2015). However, EVs are not typically charged during this time; they are charged after the last trip of the day, a pattern known as convenience charging. Tamayao et al. (2015) presents the profile of EV convenience charging (black bars in Figure 6.2.3-15) with diurnal MEF estimates for NERC regions (colored plots in Figure 6.2.3-15) for two MEF estimation methods. While in some regions the convenience charge peak coincides with a dip in MEFs (e.g., MRO), in others it does not.

Figure 6.2.3-15. Convenience Charging Profile[a] and Hourly Marginal Emission Factors[b] by National Electricity Reliability Commission Region[c]



Source: Tamayao et al. 2015

[a] Black vertical bars, left axis

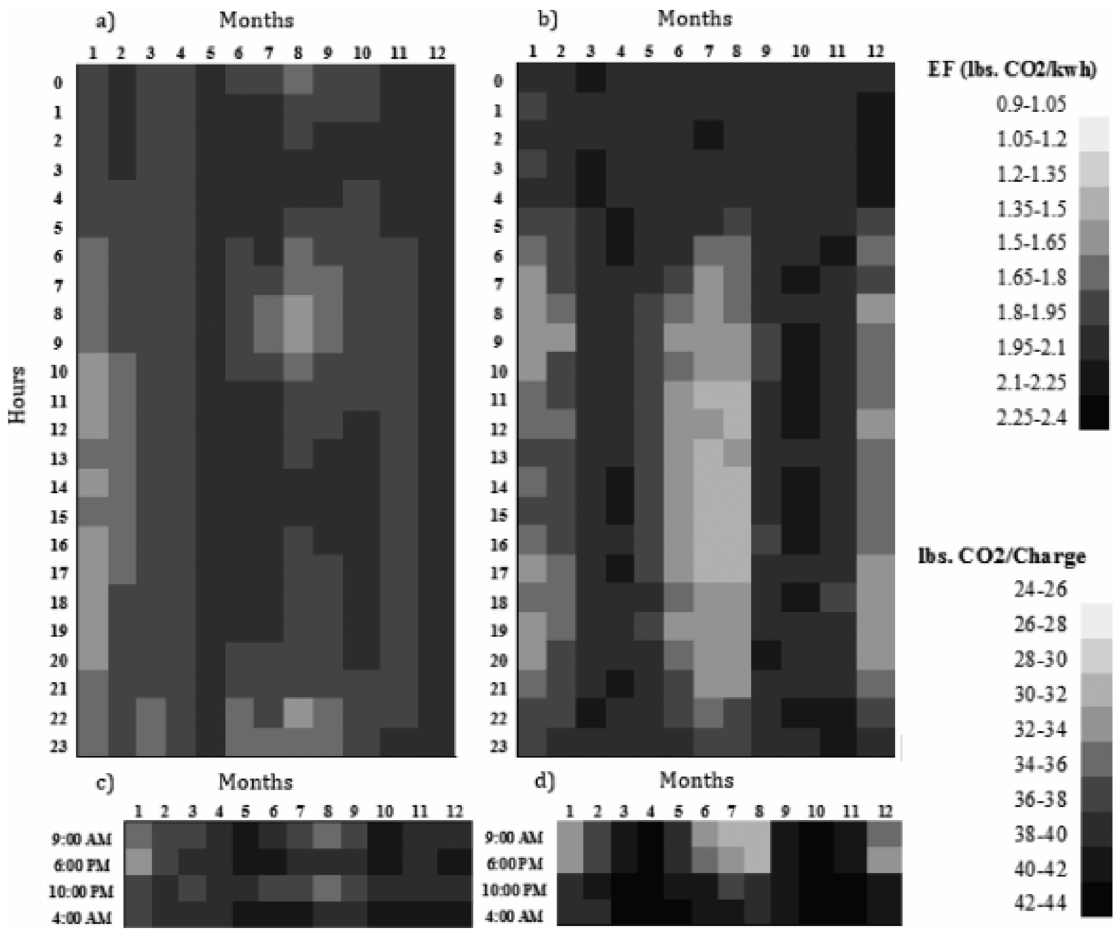
[b] Colored horizontal plots, right axis

[c] On the left MEFs are calculated using the methodology presented in Siler-Evans et al. (2012) while on the right MEF calculations use the methodology from Zivin et al. (2014)

MEF = marginal emission factor; kg/CO_2/kWh = kilograms of carbon dioxide per kilowatt-hour; NERC = National Electricity Reliability Commission; FRCC = Florida Reliability Coordinating Council; MRO = Midwest Reliability Organization; NPCC = Northeast Power Coordinating Council; RFC = Reliability First Corporation; SERC = SERC Reliability Corporation; SPP= Southwest Power Pool; TRE = Texas Reliability Entity; WECC = Western Electricity Coordinating Council

MEFs also vary over the course of the year. However, as with diurnal MEF estimates, different models produce different seasonal patterns (Ryan et al. 2016). Figure 6.2.3-16 shows results from two models, PLEXOS and AVERT, which estimate MEFs over time for the upper Midwest. While AVERT produces a clear pattern of lower MEFs during the day in winter and summer relative to spring and fall, PLEXOS does not produce the same trend and produces less variation overall (Ryan et al. 2016). Ryan et al. (2016) suggest that the minimal hourly variability in the PLEXOS model may be because PLEXOS incorporates interregional trading while AVERT does not. Because of the variability in MEF estimates, model selection and results interpretation must consider the assumptions of estimation methods (Ryan et al. 2016).

Figure 6.2.3-16. Hourly and Monthly Carbon Dioxide Emission Factors and Emissions from Electric Vehicle Charging[a, b, c, d]



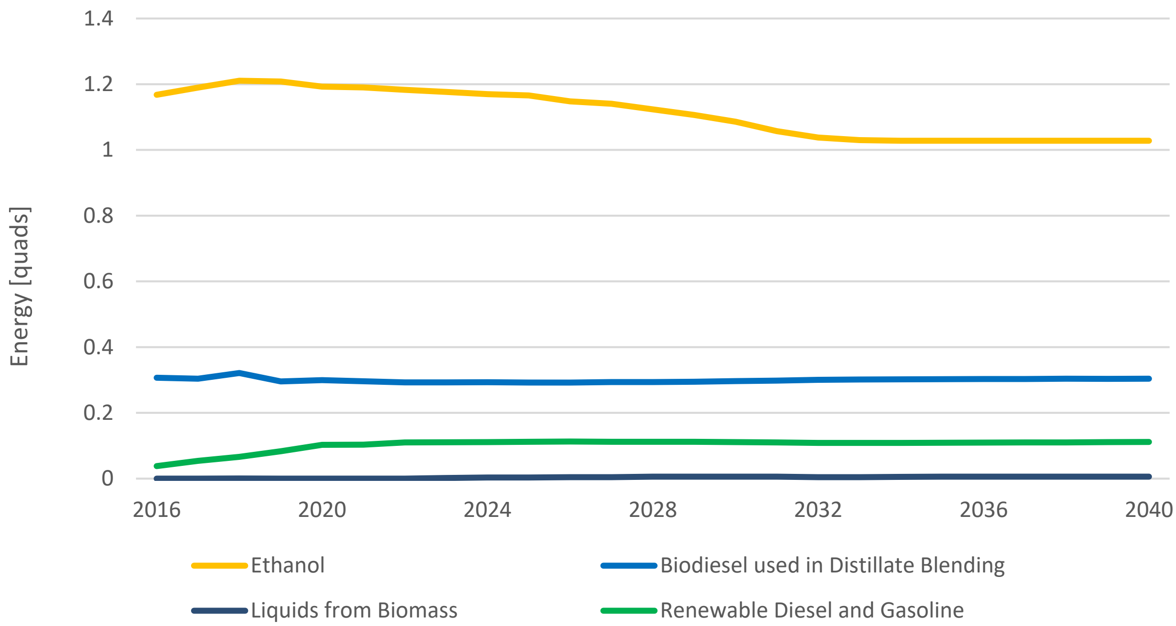
Source: Ryan et al. 2016
[a] MISO MOIL region emission factors estimated through PLEXOS
[b] Upper Midwest (WMW) region emission factors estimated through AVERT
[c] MISO MOIL emissions per charge (PLEXOS)
[d] Upper Midwest (WMW) emissions per charge (AVERT)
EF = emission factor; lbs/CO_2/kWh = pounds of carbon dioxide per kilowatt-hour

6.2.4 Biofuels

Over the past decade, the United States has seen significant increases in biofuel production due to federal legislation mandating that transportation fuel contain a minimum volume of renewable fuels, or biofuels. In 2005, the Energy Policy Act established the Renewable Fuel Standard (U.S. Government Printing Office 2005), which was expanded by the Energy Independence and Security Act of 2007 (U.S. Government Printing Office 2007). The Renewable Fuel Standard requires that transportation fuel contain a certain volume of four categories of biofuel: biomass-based diesel, cellulosic biofuel, advanced biofuel, and total renewable fuel. By 2022, the program mandates the production of 36 billion gallons of total renewable fuel.

As illustrated in Figure 6.2.4-1, ethanol is projected to make up the majority of transportation sector renewable fuel, followed by biodiesel and renewable diesel and gasoline.

Figure 6.2.4-1. Transportation Renewable Energy Projections by Source



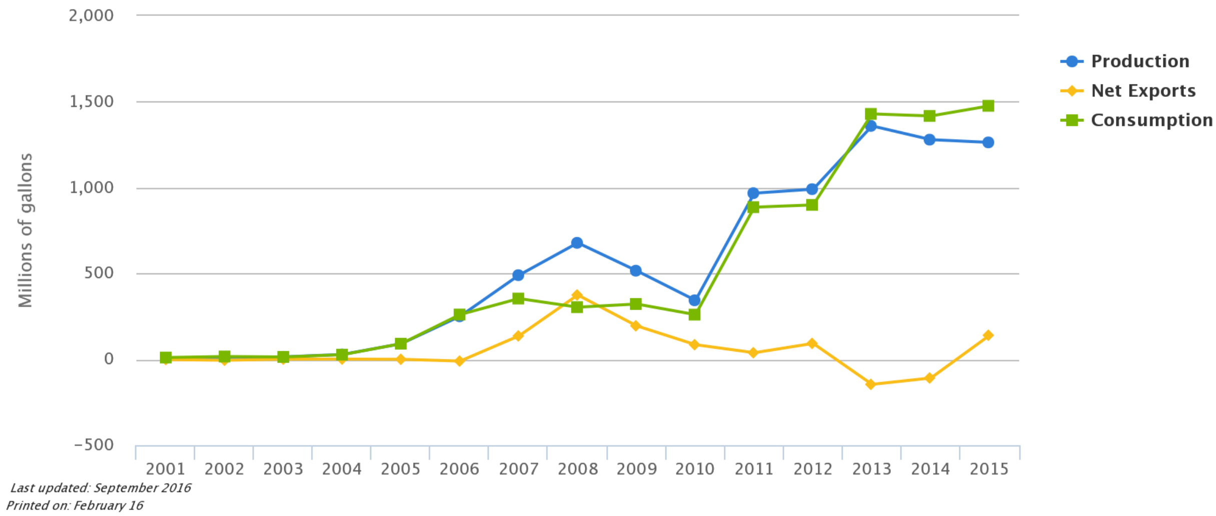
Source: EIA 2018a

Given AEO 2018 projections, the biofuel component of this literature synthesis focuses on ethanol and biodiesel. All diesel-powered passenger cars and light trucks are potential candidates for biodiesel blends.

6.2.4.1 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 causing them to react with a short-chain alcohol and catalyst to form fatty-acid methyl esters (NREL 2006). The majority of U.S. biodiesel can be combined with petroleum diesel to create different blends, the most common being B2 (2 percent biodiesel), B5 (5 percent biodiesel), and B20 (6 to 20 percent biodiesel) (AFDC 2017a). 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 (B100) must meet ASTM D6751 specifications. As illustrated in Figure 6.2.4-2, U.S. biodiesel consumption and production has increased significantly over the past 10 years.

Figure 6.2.4-2. U.S. Biodiesel Production, Exports, and Consumption



Source: EIA 2016a

B20 and other lower-concentration biodiesel blends can be used in nearly all diesel equipment with few or no engine modifications (AFDC 2017a). 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 (AFDC 2017a). Because not all engines are compatible with higher-level blends, the National Renewable Energy Laboratory recommends contacting the engine manufacturer before using them (NREL 2006). 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).

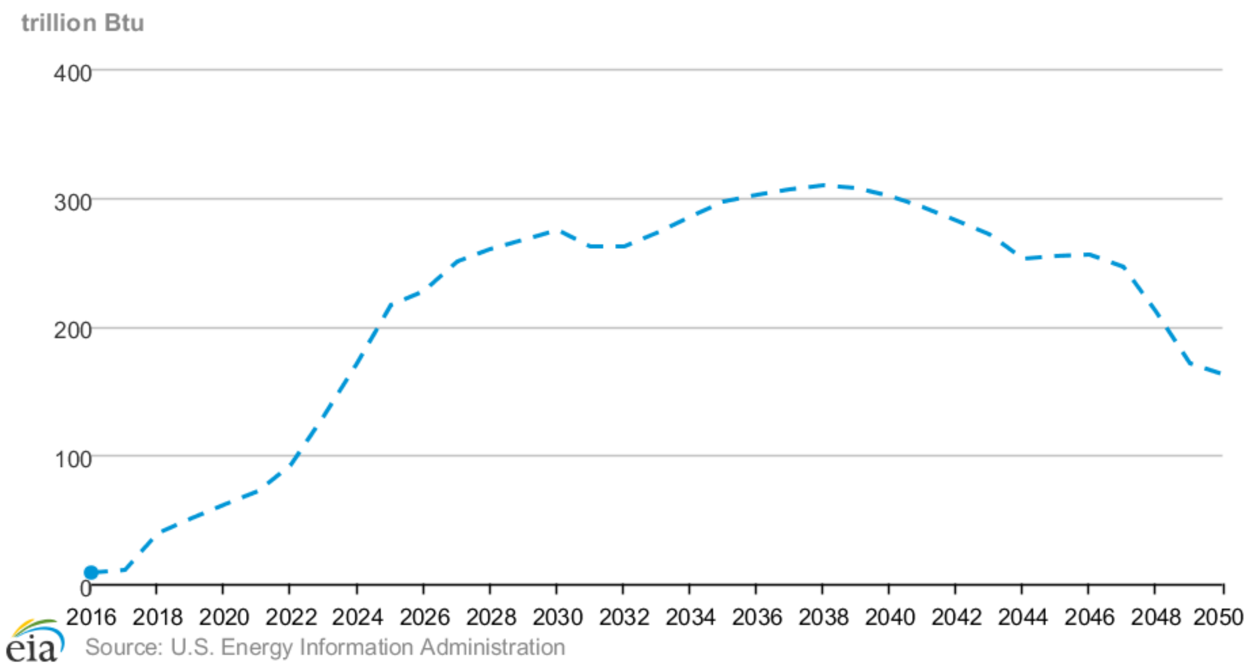
Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool shows that replacing one passenger car with a comparable model running on B20 reduces GHG emissions from 4.4 to 3.7 metric tons CO_2e annually, and replacement with a B100 vehicle reduces GHG emissions to 1.1 metric tons CO_2e annually. Similarly, Argonne National Laboratory's GREET model estimates well-to-wheels emissions for petroleum diesel and B20 biodiesel at 357 and 307 grams of CO_2e per mile, respectively. These well-to-wheels emissions assume a soybean feedstock, which has lower life-cycle CO_2 emissions than algae feedstocks. These estimates are consistent with an Argonne National Laboratory LCA that shows that GHG emissions can be decreased by up to 74 percent when using 100 percent biodiesel as a replacement for petroleum diesel (AFDC 2017a).

6.2.4.2 Ethanol

Ethanol used as an on-road vehicle fuel has the potential to reduce GHG emissions substantially, compared with conventional gasoline, depending on feedstock and blend level. The vast majority (98 percent) of ethanol produced in the United States is manufactured from corn (DOE 2015a). 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.

Corn ethanol production has increased significantly in recent years, growing by 40 percent from 2009 to 2014, to more than 14 billion gallons per year (Flugge et al. 2017). 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 (E15) and 85 percent gasoline was approved by EPA for use in conventional gasoline passenger vehicles of model year 2001 and newer. Mid-level blends containing 25 to 40 percent ethanol can be used in a high-octane fuel. High-octane fuel is designed to enable efficiency improvements that are sufficient to offset its lower energy density in a suitably calibrated and designed engine system, such as a flex fuel vehicle (Theiss et al. 2016). 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, because ethanol has a high alcohol content and can soften and degrade gaskets, seals, and other equipment in nonflexible fuel vehicles (DOE 2013b). As illustrated in Figure 6.2.4-3, E85 consumption is projected to increase through 2038.

Figure 6.2.4-3. Projected Change in Light-Duty Vehicle Ethanol Consumption



Source: EIA 2018a
Btu = British thermal units

Wang et al. (2007) found that, 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. Similarly, Canter et al. (2016) estimate that corn grain ethanol can lead to a 40 percent reduction in GHG emissions. Cellulosic ethanol can create an even larger reduction in GHG emissions: 86 percent (AFDC 2014), 82 to 91 percent (Morales et al. 2015), and 74 percent (Canter et al. 2016). The GREET model estimates well-to-wheels emissions for gasoline, E85 in a dedicated ethanol vehicle, and pure corn ethanol fuel cell vehicle to be 422, 283, and 171 grams of CO_2e per mile, respectively. A study by the Oak Ridge National Laboratory, the National Renewable Energy Laboratory, and Argonne National

Laboratory (Theiss et al. 2016) examined the impact on well-to-wheels GHG emissions from high-octane fuel vehicles resulting from miles per gallon of gasoline-equivalent (MPGGE) gains of 5 and 10 percent, various ethanol blend levels (E10, E25 and E40), and changes in refinery operation with high-octane fuel production relative to baseline E10 gasoline vehicles. Table 6.2.4-1 presents the percent change in well-to-wheels GHG emissions resulting from the high-octane fuel vehicle scenarios modeled in Theiss et al. (2016).

Table 6.2.4-1. Well-to-Wheels GHG Emissions Reductions in Vehicles Fueled by High-Octane Fuels with Different Ethanol Blending Levels Relative to Regular Gasoline (E10) Baseline Vehicles

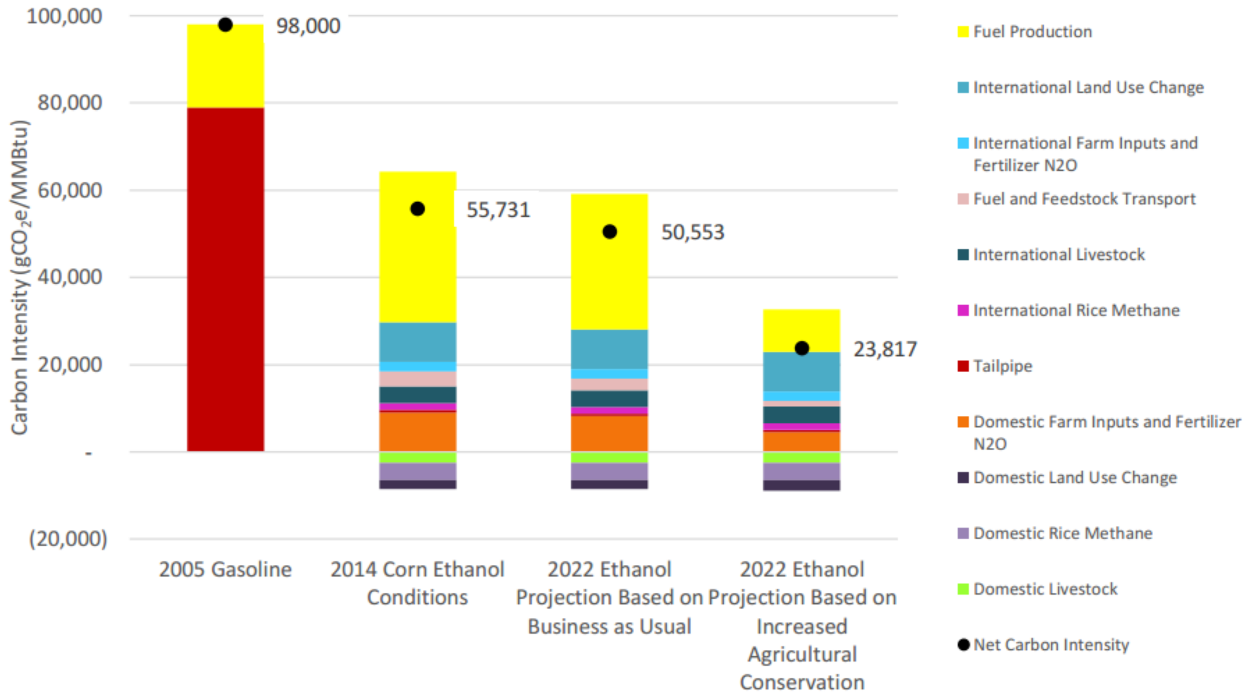
	Corn Ethanol			Corn Stover Ethanol		
Efficiency Scenario	**E10**	**E25**	**E40**	**E10**	**E25**	**E40**
5% MPGGE Gains	4%	8%	13%	6%	16%	27%
10% MPGGE Gains	8%	12%	17%	10%	20%	31%

Source: Theiss et al. 2016
MPGGE = miles per gallon of gasoline-equivalent

Flugge et al. (2017) estimated that, based on 2014 conditions, U.S. corn grain ethanol life-cycle GHG emissions are 55,731 grams of carbon dioxide equivalent per million British thermal units (g CO_2e/MMBtu), approximately 43 percent lower than those from gasoline on an energy equivalent basis (Figure 6.2.4-4). Other studies have produced similar results, including 60,000 g CO_2e/MMBtu (Canter et al. 2016) and 62,700 to 72,700 g CO_2e/MMBtu (Zhang and Kendall 2016). GHG emission estimates from corn stover (the stalks and cobs remaining after harvest) cellulosic ethanol are as low as 26,000 g CO_2e/MMBtu (Canter et al. 2016), 15,400 to 33,900 g CO_2e/MMBtu (Zhang and Kendall 2016), and 21,000 to 32,000 g CO_2e/MMBtu (Murphy and Kendall 2015).

By 2022, the carbon intensity of corn grain ethanol is projected to decline from 2014 levels by nearly 10 percent under a business as usual scenario and by nearly 60 percent under a scenario with increased agricultural conservation, making ethanol 48 percent to 76 percent less GHG-intensive than gasoline (Flugge et al. 2017).

Figure 6.2.4-4. Greenhouse Gas Profiles of Gasoline and Corn Ethanol



Source: Flugge et al. 2017
G CO_2e/MMBtu = grams of carbon dioxide equivalent per million British thermal units; N_2O = nitrous oxides

As illustrated in Figure 6.2.4-4, the largest components of the Flugge et al. (2017) corn ethanol life-cycle GHG profile for 2014 conditions include fuel production (62 percent, 34,518 g CO_2e/MMBtu), domestic farm inputs and fertilizer (16 percent, 9,065 g CO_2e/MMBtu), and international land use change (16 percent, 9,082 g CO_2e/MMBtu). Previous studies have estimated similar GHG profiles for corn ethanol production, including 28 g CO_2e/MJ (EPA 2010d), 30 g CO_2e/MJ (Wang et al. 2012), 15 to 20 g CO_2e/MJ (Wang et al. 2015), and 20 to 35 g CO_2e/MJ (Boland and Unnasch 2014). Boland and Unnasch (2014) estimated that production using biomass produces a 10 g CO_2e/MJ emission intensity. Ethanol production GHG intensity declined by 4 percent from 2010 to 2014, and is projected to decline by 8 to 20 percent from 2012 to 2022 (Boland and Unnasch 2014, Flugge et al. 2017) because of improved technology and the development of new coproducts.

Corn ethanol can be produced by either dry milling or wet milling (Flugge et al. 2017). In dry milling, the entire corn kernel is ground and fermented to produce ethanol. In wet milling, the corn kernel is soaked to separate the starch from the kernel, and the starch is then used to make ethanol. In the United States, dry milling is the primary method of producing corn ethanol.

6.2.5 Fuel Cells

Fuel-cell vehicles are fueled by hydrogen that is converted to electricity via a fuel cell. The fuel cell is similar in structure to an EV battery, but active components (i.e., cathode, anode, and electrolyte) use different materials. Fuel-cell vehicles emit no GHG or air pollutants when operating because the chemical conversion of hydrogen to electricity generates only water and heat. However, upstream fuel production (well-to-tank) of hydrogen from natural gas or grid electricity, plus compression and cooling, can yield significant GHG and air pollution emissions (Elgowainy et al. 2016). Life-cycle emissions vary widely based on this hydrogen production technology (Nitta and Moriguchi 2011).

Hydrogen is most commonly produced using steam methane reforming, but can also be produced with water electrolysis (using grid electricity) or biomass gasification. In transportation and distribution, electricity is required for compression and conditioning of hydrogen for eventual refueling and vehicle storage (Elgowainy et al. 2016). Using steam methane reforming, GREET estimates the well-to-wheel GHG emissions for a fuel-cell vehicle to be 156 g CO_2e/MJ using default inputs. Fuel production, which encompasses all well-to-tank activities after natural gas is delivered to the production plant, accounts for 93 percent of life-cycle emissions (ANL 2016).

Numerous factors limit fuel-cell vehicle manufacture and consumer adoption, namely the cost and the lack of a hydrogen distribution infrastructure (National Research Council 2013). The CAFE model for this EIS projects that light-duty hydrogen fuel consumption in 2050 would range from 0.02 percent of total fuel consumption under Alternative 1 to 0.07 percent of total fuel consumption under the No Action Alternative.

Ongoing research and development is currently targeting breakthroughs to reduce the cost of hydrogen distribution infrastructure by a factor of two by 2025. It is possible that additional demand for hydrogen in transportation can be established by emerging applications such as synthetic fuels, which are being explored by DOE's H2@Scale initiative (DOE 2018b).

6.3 Materials and Technologies

This section reviews LCA literature related to six broad categories of materials and technologies that can improve passenger car and light truck fuel efficiency.

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. Hot-wire laser welding requires 16 percent less energy than cold-wire laser welding (Wei et al. 2015). Sproesser et al. (2015) conducted an LCA of four different welding processes. Manual metal arc welding had the highest environmental impact as it consumes more material and electricity per a given weld seam length than the other three processes. This is because it has a low deposition rate and welding speed compared to the other processes. Automatic laser-arc hybrid welding had the lowest global warming potential, as it consumed the least electricity and material during operation (Sproesser et al. 2015). The study notes that laser-arc welding requires a critical overall weld seam length to become environmentally beneficial compared to alternative methods, due to differences in the filler material for each method (Sproesser et al. 2015). Another 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. Hydroforming requires fewer moldings and lighter parts than typical die forming processes. The process allows manufacturers to produce entire components in a single process that would otherwise be made using multiple parts joined together. 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).[10] The use of hydroforming to manufacture a hollow crankshaft reduced material usage by 87 percent and weight by 57 percent, compared to a solid shaft with the same torque formed with conventional welding techniques (Shan et al. 2012). Hydroforming has reduced the weight of several other parts, such as shift beams, doors, and various frame components (Shinde et al. 2016).

6.3.1.3 Tailor-Welded Blanks

Tailor-welded blanks are a weight-saving technology in which two or more sheet pieces with different shapes, gages, and material specifications are welded together so that the ensuing subassembly is lighter and has few components (Merklein et al. 2014). 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 Aluminum Casting and Extrusion

Both die-casting and extrusion offer an alternative way to produce aluminum parts instead of the more traditional method of stamping. To die cast a part, molten metal is injected into a mold, called the die. To extrude a part, aluminum is forced through a mold. Casting allows manufacturers to create equally strong parts with less material relative to stamping. Aluminum casting can also reduce the total number of components used in assembly (Shinde et al. 2016). One study examining the production of a cast aluminum crossbeam found its weight to be 50 percent less than its steel counterpart (Cecchel et al. 2016).

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 materials reduces vehicle fuel consumption but also could increase the upstream environmental burden associated with producing these materials. A literature review of vehicle mass reduction LCAs found that overall life-cycle energy use will decline for passenger cars and light trucks through use-phase fuel economy benefits of material substitution, but will increase upstream energy use in material production (Hottle et al. 2017). This tradeoff is often measured by the material's breakeven distance. Breakeven distance is the mileage at which the use-phase energy reductions outweigh any increases in the extraction and manufacturing life-cycle phases (Das 2014, Kelly et al. 2015).

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[10] Kocańda and Sadłowska (2008) did not perform an LCA of hydroforming but instead discussed the mass savings achieved from the production technology.

A study by Kelly et al. (2015) compared the life-cycle impacts of material substitution; specifically, of replacing steel with one of four lightweight materials: advanced high-strength steel, magnesium, polymer composites (both carbon fiber-reinforced polymer, and glass fiber-reinforced polymer), and two types of aluminum (cast and wrought). Life-cycle impacts and driving breakeven distance for each material were calculated for two different fuel reduction values representing cases with or without powertrain adjustments (0.15 to 0.25 and 0.25 to 0.5 liter per 100 kilometers by 100 kilograms), respectively). The authors used the GREET2 model for energy and emissions data and for modifying vehicle models to explore the substitution impacts. Material substitution ratios were obtained separately from a U.S. Department of Energy report (DOE 2013d). Magnesium, cast aluminum, and wrought aluminum had breakeven distances under 100,000 kilometers (62,000 miles) regardless of fuel reduction values, except for the highest substitution ratio scenarios for wrought aluminum and magnesium. In general, cast aluminum demonstrated the lowest breakeven distance among those three. Carbon fiber-reinforced polymer had a breakeven distance of more than 100,000 kilometers (62,000 miles) for several scenarios but could be less than 50,000 kilometers (31,000 miles) in multiple scenarios using the low subsitution ratio. Glass fiber-reinforced polymer fared the best of all materials, having breakeven distances of less than 10,000 kilometers (6,200 miles) for all scenarios (Figure 6.3.2-1).

Figure 6.3.2-1. Breakeven Driving Distance for Different Material Substitution Pairs and Substitution Ratios

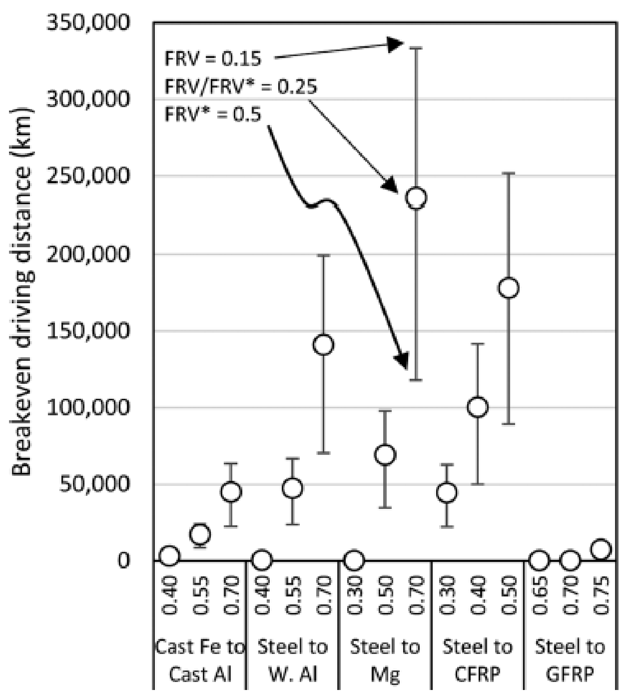

Figure 5. Breakeven driving distance for different material substitution pairs and substitution ratios, assuming different FRV/FRV* values.

Source: Kelly et al. 2015
FRV = fuel reduction values; km = kilometers; Fe = iron; Al = aluminum; W. Al = wrought aluminum; Mg = magnesium; CFRP = carbon fiber-reinforced polymer; GFRP = glass fiber-reinforced polymer

A comprehensive review of vehicle lightweighting LCAs examined the range of estimated fuel savings from almost 50 studies and models for 3 different vehicle types (i.e., internal combustion vehicles, HEVs, and BEVs). The study found that fuel reduction estimates varied significantly when reducing overall vehicle weight by 100 kilograms. The authors studied the effect of different variables on life-cycle fuel reduction including powertrain size, vehicle class (e.g., car, sport-utility vehicle), and driving settings (i.e., city or highway). The results show that driving settings had the greatest influence on overall fuel savings, with mass reduction leading to larger fuel savings during city driving and significantly lower fuel savings (60 to 90 percent less savings) during highway driving. Powertrain sizing also had a significant impact, but vehicle class showed little variation in results (Luk et al. 2017).

6.3.2.1 Aluminum and High-Strength Steel

Aluminum, which is used intensively in the transportation sector, has a high strength-to-weight ratio, corrosion resistance, and processability. (Cheah et al. 2009). High-strength steel has the same density as conventional steel but provides greater strength; thus, 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. High-strength steel provides the greatest weight-reduction benefits in structural or load-bearing applications, where strength is a key factor in material selection (Cheah and Heywood 2011, Kim et al. 2010b, Koffler and Provo 2012, Mohapatra and Das 2014).

Nineteen studies[11] examine the life-cycle impacts of substituting aluminum and/or high-strength steel for mild steel components in vehicles (Kim et al. 2010a, Hakamada et al. 2007, Bertram et al. 2009, Dubreuil et al. 2010, Cáceres 2009, Stodolsky et al. 1995, Lloyd and Lave 2003, Geyer 2008, Birat et al. 2003, Weiss et al. 2000, Bandivadekar et al. 2008, Ungureanu et al. 2007, Mayyas et al. 2012, Liu and Muller 2012, Shinde et al. 2016, Kelly et al. 2015, Das 2014, Modaresi et al. 2014, Raugei et al. 2015). Some of these (Bertram et al. 2009, Geyer 2008, Lloyd and Lave 2003, Hakamada et al. 2007, Mayyas et al. 2012, Kelly et al. 2015) focus on material substitution in specific vehicle components. Other studies estimate overall mass reduction from material substitution and vehicle redesign (Weiss et al. 2000, Bandivadekar et al. 2008, Ungureanu et al. 2007, Kim et al. 2010a, Das 2014). The studies show the following trends:

- **Net energy reduction.** In general, the reduced energy use and GHG emissions during the use phase of aluminum and high-strength steel material substitution is greater than the increased energy use and GHG emissions needed to manufacture these lightweight materials at the vehicle production phase; thus, a net energy reduction ensues.
- **Variables affecting reduced energy consumption and emissions.** The magnitudes of life-cycle GHG emissions reductions and energy-use savings are influenced by the amount of recycled material used in vehicle components, end-of-life recycling rate, lifetime of vehicles in use, and location of aluminum production.

On a fleet-wide scale, substituting aluminum for steel in body panels in one year's sales volume of vehicles in the United States in 2000 (16.9 million vehicles) would, according to one study, have led to a

[11] The following studies in this literature review indicated that they relied—at least partially—on industry funding or industry-funded data to evaluate the life-cycle impacts of aluminum and high-strength steel material substitution: Kim et al. (2010a), Geyer (2007, 2008), Dubreuil et al. (2010), Das (2014), and Birat et al. (2003). All of the studies reviewed have undergone peer review for publication in academic journals. Certain studies noted where critical reviews were conducted in accordance with ISO 14044 standards on either the method (Geyer 2008) or life-cycle inventory inputs (Dubreuil et al. 2010), or where critical review was not performed (Bertram et al. 2009).

decrease in 3.8 million tons of GHGs over the life cycle of the vehicles (Lloyd and Lave 2003). The impacts of a future fleet with a more aluminum-intensive design than currently implemented could result in global annual savings as high as 1 gigaton CO_2e annually by 2050 (Modaresi et al. 2014). One study comparing aluminum substitution for mild-steel and cast iron components in individual cars and fleets showed that the additional CO_2 emissions from the production of aluminum for aluminum castings were offset by fuel savings in 2 to 3 years of vehicle use. CO_2 emissions from aluminum beams and panels were offset in 4 to 7 years of vehicle use (Cáceres 2009).

The U.S. Department of Energy funded a project, completed in 2015, to design and build an aluminum-intensive lightweight vehicle called the Mach I. This vehicle achieved a 364-kilogram mass savings over a 2013 Ford Fusion by primarily using aluminum in place of iron and steel. Bushi et al. (2015) performed an LCA as part of the project, finding a 16 percent reduction in life-cycle GHG emissions from the 2013 Fusion (68,500 kilograms CO_2e) to the Mach I (57,600 kilograms CO_2e), and a 16 percent reduction in life-cycle primary energy use (156,000 megajoule in savings). These savings stemmed from a 21 percent increase in the Mach I's fuel economy over the Fusion (increase of 6 miles per gallon) (Bushi et al. 2015).

Other research has focused on the breakeven driving distance. Depending on which parts are substituted and the amount of material displaced, studies estimated that aluminum parts substituting for steel parts have a breakeven distance between 19,000 and 160,000 miles (Das 2014, Kelly et al 2015, Mayyas et al 2012). The lower end of that range equates to approximately 1 year of vehicle lifetime (Das 2014). In a study comparing the total life cycle emissions impacts of several different lightweight materials compared to a steel baseline, aluminum showed the greatest potential reduction (Raugei et al. 2015).

In addition to vehicle mileage, many studies emphasize the sensitivity of LCA results to the amount of recycled material used in automobile components and the materials recycling rate at end of life (Mayyas et al. 2012, Raugei et al. 2015). Substituting rolled aluminum or high-strength steel for mild-steel sheet parts reduces the total life-cycle GHG emissions. The savings in aluminum results can depend on scrap recycling rather than just vehicle fuel economy improvement (Geyer 2008). Life-cycle GHG savings from aluminum component substitution also depends heavily on the location of aluminum production and the share of secondary aluminum used (Kim et al. 2010a).

In practice, recycling aluminum results in the accumulation of impurities, typically other metals that are challenging and energy-intensive to remove. Consequently, recycled aluminum is usually blended with primary aluminum to mitigate the buildup of contaminants. This practice results in an effective cap on the share of post-consumer aluminum that can be in recycled aluminum (Gaustad et al. 2012). A report using material flow analysis and industry data estimated that more than 90 percent of automotive aluminum is recycled in an open-loop system (Kelly and Apelian 2016).

GHG emissions savings from vehicles using lightweight materials might or might not depend on the materials recycling rates achieved. Estimates range from lower life-cycle GHG emissions only under scenarios with very high recycling levels for aluminum components, to significantly lower life-cycle GHG emissions compared to comparable mild-steel components, even with an unrealistic recycling rate of 0 percent (Bertram et al. 2009, Birat et al. 2003). One study found that an aluminum chassis substituted for a steel chassis resulted in net GHG savings under all recycling scenarios. The recycling scenarios ranged from *pessimistic*, where 75 percent of aluminum parts are open-loop recycled and 25 percent landfilled, to *optimistic*, where 90 percent of aluminum parts are closed-loop recycled (Raugei et al. 2015). Another study noted that replacing conventional steel with recycled aluminum for various frame components reduced life-cycle emissions of CO_2 by 7 percent within 1 year and 11 percent after 10 years of use (Ungureanu et al. 2007).

One study suggested that secondary sources of aluminum (recycled aluminum from landfill or urban mining) will likely be easier to access in the future than primary aluminum (from bauxite mining) (Chen and Graedel 2012a). This trend suggests that the quality of secondary aluminum will affect the cost and supply of primary aluminum used in vehicles in the future. Aluminum alloy scrap includes alloy elements, which degrade the quality of the material when recycled. Avoiding quality degradation will require processors to identify and segregate alloys at the point of discard so the alloy can be reused as originally designed (Chen and Graedel 2012b). An aluminum smelter's location also affects 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 emission factors depending on how and where the electricity is generated (Colett 2013).

6.3.2.2 Plastics

Plastics, also known as polymers, include thermosets, thermoplastics, and rubber materials (Park et al. 2012). Because plastics are typically not as strong as metal or carbon fiber-reinforced plastics, they are typically used for interior or exterior parts that do not have structural strength requirements, such as bumpers, lighting, trim parts, or instrument panels (Park et al. 2012). Plastics tend to be lightweight, resistant to corrosion and electricity, have a low thermal conductivity, and are formable. They are typically cheaper than aluminum and high-strength steel and lighter than conventional steel (Munjurulimana et al. 2016 citing McKinsey 2012). An EPA study on weight reduction strategies proposes several instances in which plastic could be substituted for steel parts. Substitution of plastic for steel in parts such as the oil pan, water pump, and fasteners can reduce weight by 25 percent to 80 percent for the individual parts (EPA 2014e). Few LCA studies quantify the life-cycle benefits of plastic substitution. One study conducted a cradle-to-cradle LCA (the full life cycle and recycling at the end of life) of replacing a steel fender with a thermoplastic resin fender (Baroth et al. 2012). They found that the plastic fender resulted in up to 47 percent lower carbon footprint than its steel counterpart. These emission reductions predominantly occurred during the use phase, where the emissions from the vehicle with the plastic fender (91.7 kilograms [202 pounds] of CO_2) were much lower than the vehicle with the steel fender (200 kilograms [440 pounds] of CO_2).

6.3.2.3 Polymer Composites

Various types of reinforced polymer composites are in use or in development as substitutes for mild steel or aluminum, predominantly in vehicle body panels. These materials offer added tensile strength and weight-reduction potential compared to mild steel.[12] They include glass- and carbon-fiber-reinforced polymer composites and nanocomposites, such as those reinforced with nanoclays or carbon nanotubes (Lloyd and Lave 2003, Cheah 2010, Park et al. 2012). At the nano scale, carbon fibers offer additional tensile strength and provide other functionalities such as electrical conductivity and antistatic properties, which are useful properties for automobile components such as body panels and casings for electronic equipment (Khanna and Bakshi 2009).

[12] Estimates of the weight reduction in automobile body parts range from 38 to 67 percent (Overly et al. 2002, Cheah 2010, Lloyd and Lave 2003, Khanna and Bakshi 2009).

Eighteen studies examine the life-cycle environmental impacts of substituting reinforced polymers or composites for aluminum or mild-steel components in vehicles (Lloyd and Lave 2003, Khanna and Bakshi 2009, Cheah 2010, Overly et al. 2002, Gibson 2000, Weiss et al. 2000, Sullivan et al. 2010, Das 2011, Keoleian and Kar 1999, Tempelman 2011, Spitzley and Keoleian 2001, Boland et al. 2014, Raugei et al. 2015, Koffler and Provo 2012, Deloguet al. 2015, Witik et al. 2011, Mayyas et al. 2012, Kelly et al. 2015). Two of these studies (Lloyd and Lave 2003, Khanna and Bakshi 2009) focus on applications based on nanotechnology. The studies show the following trends:

- 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 energy- and GHG-intensive 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 parts 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 are. 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.

Several studies show that the upstream extraction, materials processing, and manufacturing stages for carbon-fiber- and glass-fiber-reinforced composites used in vehicles are more energy- and GHG-intensive than those for conventional (mild) steel, but less than those for aluminum (Overly et al. 2002,[13] Cheah 2010, Weiss et al. 2000, Gibson 2000, Tempelman 2011, Khanna and Bakshi 2009, Raugei et al. 2015, Koffler and Provo 2012). For example, estimates of the cradle-to-gate[14] energy required for carbon nanofiber polymer composites range from nearly 2 to 12 times greater than the energy requirements for steel[15] (Khanna and Bakshi 2009). Other estimates of cradle-to-gate energy indicate that carbon-fiber production is almost 20 times more energy intensive than conventional galvanized steel, and 15 times more CO_2 intensive on a weight basis (Das 2011). According to one study, in relation to aluminum used in automobile bodies, polymer composites require less primary energy and are

[13] Note that Overly et al. (2002) include extraction and material processing, but not manufacturing, in the study scope due to data limitations, but note that the impacts are typically the smallest during this stage.

[14] Including carbon nanofiber production, polymer resin production, carbon nanofiber dispersion, and composite manufacture; excluding vehicle use and associated gasoline production and the end-of-life stages.

[15] Standard steel plate used in this study.

associated with lower GHG emissions;[16] however, if recycled aluminum is used, the energy requirements and upstream GHGs are comparable to that of polymer composites (Weiss et al. 2000). One study analyzed the cradle-to-gate emissions associated with a traditional steel vehicle and a lightweight vehicle composed of magnesium structural components and plastic composite nonstructural components. The material production emissions for the magnesium-plastic composite car were almost double those of the steel vehicle (Raugei et al. 2015).

While polymer composites used in vehicle body panels are more energy- and GHG-intensive to produce compared to mild steel and, in some cases aluminum, inclusion of the product use phase results in net life-cycle energy savings and reduced GHGs. This crossover occurs sometime during the lifetime of the vehicle (Gibson 2000, Deloguet al. 2015). One study estimates that substituting a high-performance clay-polypropylene nanocomposite for steel in a passenger car or light truck could reduce life-cycle GHG emissions by as much as 8.5 percent and that GHG emissions associated with material production of that high-performance material are 380 times smaller than GHG emissions associated with vehicle use[17] (Lloyd and Lave 2003). This energy and GHG reduction is a result of the significant reductions in vehicle weight and the subsequent improvements in fuel economy. A study by PE International for American Chemistry Council notes that a 66 percent reduction in part weight by switching from steel to glass-reinforced plastic results in a decrease in use-phase emissions (74.01 kg CO_2e/part) (Koffler and Provo 2012).

In general, the studies that examine multiple environmental impact categories conclude that these lightweight composite materials offer overall environmental benefits compared to mild steel—and in most cases, compared to aluminum—across the vehicle life cycle. Carbon-fiber-reinforced polymer composite used in vehicle closure panels[18] show fewer environmental impacts compared to steel, aluminum, and glass-fiber-reinforced polymer composite in most impact categories—including nonrenewable and renewable resource use, energy use, global warming potential, acidification, odor/aesthetics, water quality (biochemical oxygen demand), and landfill space (Overly et al. 2002). When substituting small parts, glass-fiber-reinforced polypropylene has a lower breakeven distance over magnesium, carbon-fiber-reinforced polypropylene, and welded aluminum when replacing steel. These results vary based on the substitution ratios used and whether powertrain resizing is considered (Kelly et al. 2015). When analyzing fiber-reinforced polypropylene and polyamide, one study found that a majority of the eutrophication and acidification came from material production instead of the use phase, unlike global warming potential (Deloguet al. 2015 However, glass-reinforced polymer composite manufacturing can have greater acidification than steel manufacturing (Koffler and Provo 2012).

Other studies note additional carbon composite benefits in air emissions, water emissions, and hydrogen fluoride emissions over the entire vehicle life cycle compared to mild steel and aluminum (Gibson 2000). A clay-polypropylene nanocomposite substituted for steel shows reduced life-cycle environmental impacts across all impact categories (including electricity use, energy use, fuel use, ore use, water use, conventional pollutants released, global warming potential, and toxic releases and transfers), except for a slight increase for hazardous waste generation (Lloyd and Lave 2003). The lower impacts are largely because the vehicle production requires less material with the lighter material.

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[16] This upstream energy and GHG impact for a plastic automobile body is approximately about one-third of that of one with virgin aluminum components (Weiss et al. 2000).

[17] Including petroleum production, which refers to the upstream emissions associated with producing the petroleum that the vehicles consume.

[18] Includes four door panels, the hood, and the deck lid.

When carbon-fiber-reinforced polymer replaces a much larger share of the steel in the vehicle body panel (i.e., beyond the closure panels), the environmental benefits of carbon fiber lessen (Overly et al. 2002). When a nylon composite manifold was compared to two similar aluminum parts (sand-cast and multi-tubed brazed), the composite manifold showed lower life-cycle impacts across certain metrics (energy use and GHG, carbon monoxide, nonmethane hydrocarbons, and NO_X emissions), but increases among others (methane, PM10, and sulfur dioxide) relative to one or both of the aluminum manifolds (Keoleian and Kar 1999). Two other studies featuring manifolds show similar results (Rageui et al. 2015, Deloguet al. 2015).

Studies acknowledge that large uncertainties underlie the results and that certain assumptions have a significant influence on the results. For example, consideration of fleet effects, such as upstream production energy mix (e.g., the high share of hydropower used in the production of aluminum), could change the results (Lloyd and Lave 2003, Spitzley and Keoleian 2001). The substitution ratio used for magnesium substituting steel can vary the breakeven distance by approximately 225,000 kilometers (140,000 miles) (Kelly et al. 2015). If a component is large enough, the powertrain may need to be resized, leading to additional weight reduction benefits (Kelly et al. 2015, Kim et al. 2015). Studies handled the impacts from end of life in different ways (e.g., assuming composites were landfilled at end of life [Overly et al. 2002] or excluding the impacts altogether [Khanna and Bakshi 2009]). Studies noted that a more complete analysis would look at impacts associated with recycling composites and the effect of using recycled versus virgin material inputs in their production (Lloyd and Lave 2003, Weiss et al. 2000, Witik et al. 2011) and would consider reparability and replacement impacts (Lloyd and Lave 2003, Overly et al. 2002, Koffler and Provo 2012). Composites demonstrate lower recyclability than metals, but this is partially offset by their high energy content for the purposes of incineration. If waste-to-energy disposal is not an option for composite auto body components, the low recyclability of these materials results in significantly more life-cycle waste generation than their metal alternatives (Tempelman 2011). Incineration has lower life-cycle impacts for composite materials than landfilling as the material avoids the longer-term release of methane during the anaerobic degradation of material (Witik et al. 2011), but these benefits could be diminished if composite-based panels need to be discarded and replaced especially frequently.

6.3.2.4 Magnesium

Magnesium is an abundant metal with a density that is approximately 20 percent that of steel and approximately 60 percent that of aluminum. At present, on average, magnesium content per vehicle is approximately 5 kilograms (11 pounds), but it is estimated that this average content will double to approximately 10 kilograms (22 pounds) by 2020 (Cheah 2010). Magnesium-substituted vehicles have higher fuel efficiencies than conventional and aluminum-substituted vehicles due to lighter vehicle weights from magnesium's low density (Hakamada et al. 2007, Cáceres 2009, Shinde et al. 2016). On average, magnesium provides a 60 percent weight reduction over steel and 20 percent over aluminum, with equal stiffness (Cheah 2010, Easton et al. 2012).

Magnesium is abundant throughout Earth's upper crust, although it does not occur naturally in its isolated form. Instead, magnesium is typically refined from salt magnesium chloride using electrolysis or from ore (mainly dolomite) using the Pidgeon process, which involves reducing magnesium oxide at high temperatures with silicon. The majority (85 percent) of the world's magnesium is produced via the Pidgeon process in China (Johnson and Sullivan 2014). In general, magnesium is more expensive and energy-intensive to produce than steel.

Twelve studies examined the life-cycle environmental impacts of substituting magnesium for steel and aluminum components in vehicles (Hakamada et al. 2007, Dubreuil et al. 2010, Cheah 2010, Tharumarajah and Koltun 2007, Sivertsen et al. 2003, Cáceres 2009, Witik et al. 2011, Ehrenberger 2013, Easton et al. 2012, Raugei et al. 2015, Li et al. 2015, and Kelly et al. 2015). Overall, the studies show the following trends:[19]

- Magnesium is more energy- and GHG-intensive to produce than steel or aluminum.
- Significant reductions in vehicle weight and GHG emissions can be achieved in the future by substituting magnesium for heavier components currently in use. However, breakeven distances can be relatively high in relation to other materials (Kelly et al. 2015). For example, examining only mass reduction of the engine block, use of coal-based Pidgeon process magnesium could result in a breakeven distance of from approximately 20,000 kilometers (12,500 miles) to 236,000 kilometers (147,000 miles) compared to other materials ranging from iron to aluminum produced from different production processes and locations (Tharumarajah and Koltun 2007). The use of coal-based Pidgeon process magnesium decreases the life-cycle energy and GHG benefits of magnesium. The greater the amount of GHG-intensive Pidgeon process magnesium incorporated into the vehicle, the longer the break-even distance becomes (Cáceres 2009).
- If a large proportion of recycled magnesium is used, the production energy and GHG disadvantages of using magnesium can be significantly offset (Hakamada et al. 2007). Generally, the higher the proportion of recycled magnesium, the shorter the breakeven distance.
- Several of the studies looked at the effects of replacing particular automotive parts. Given the heterogeneity of the studies, it is difficult to make conclusive statements, but which part of the automobile is substituted could make a difference to LCA results. In general, however, weight reduction is probably the primary consideration in use-phase GHG emissions, and which parts are replaced will be subject mostly to engineering considerations (Hakamada et al. 2007).

The LCA literature generally agrees that magnesium substituted in vehicles requires more energy to produce than conventional and aluminum-substituted vehicles, and therefore produces more GHGs during that phase (e.g., Dubreuil et al. 2010, Tharumarajah and Koltun 2007). Both electrolysis and the Pidgeon process are energy intensive, although electrolysis is three to five times more energy efficient than the Pidgeon process, in part because electrolysis is often powered by hydroelectricity or other lower-carbon energy sources (Cheah 2010). In addition, three potent GHGs are used during primary metal production: sulfur hexafluoride and two perfluorocarbons (Dhingra et al. 2000). Sulfur dioxide is also used as a protective gas to cover molten magnesium during production (i.e., cover gas) (Dubreuil et al. 2010).

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). These toxicity impacts can result from fuel consumption, materials manufacturing, or other supply chain activities associated with the different materials. Human toxicity impacts of the magnesium material and manufacturing

[19] Differences in scope and functional units (i.e., the reference unit against which environmental impacts are compared) across the studies limit their comparability with each other. For example, modeling different magnesium production processes and recycled contents has a great effect on the life-cycle emissions. Assumptions about which parts are replaced or supplemented with magnesium vary widely across studies, as do methods such as the weight-for-weight ratio at which magnesium is substituted for steel.

phase are greater than the toxicity benefits achieved from reduced fuel consumption due to lightweighting during the use phase relative to steel (Witik et al. 2011).

Even considering the energy required to produce magnesium, several LCAs have found that, over vehicle life, the high fuel efficiency of magnesium-substituted vehicles lowers total energy use below that of conventional and aluminum-substituted vehicles. The degree of energy savings is determined by which vehicle parts are substituted and the methods used in manufacturing the magnesium. The results of each LCA vary depending on which component in the vehicle was substituted and which manufacturing methods were used. The following key assumptions affect life-cycle environmental impacts associated with magnesium substitution.

- **Method of magnesium production**. Assumptions about what proportion of magnesium comes from the Pidgeon process and what portion from electrolysis, as well as the assumed fuel sources, will have an effect on GHG emissions and energy use, because the Pidgeon process is more energy and GHG intensive. The Pigeon process is improving; a 2015 study calculated that the process emitted 38 to 48 percent less CO_2 per ton of magnesium than previously estimated, and emissions are predicted to fall further (Li et al. 2015). This implies that older LCA studies are likely to underestimate the LCA benefits of magnesium substitution.
- **Sulfur hexafluoride (SF_6).** SF_6 is a potent GHG[20] and might be phased out of manufacturing in the near future in most countries. At present, SF_6 is used as a cover gas (i.e., a protective gas to cover molten magnesium during production). To lower GHG emissions, sulfur dioxide can also be used to treat magnesium, but it is toxic (Johnson and Sullivan 2014). The inclusion of SF_6 as part of the emission impacts from manufacturing can increase the vehicle breakeven point to approximately 200,000 kilometers (124,000 miles) (Sivertsen et al. 2003). The inclusion of sulfur dioxide as part of the emission impacts from manufacturing leads to a vehicle breakeven point of approximately 67,000 kilometers (41,600 miles) (Sivertsen et al. 2003). One study comparing the life-cycle impacts of a magnesium body and chassis to a steel baseline estimated that variations in SF_6 use in manufacturing for magnesium parts (from high use to no use) can yield approximately a 30 percent change in life cycle emissions. Furthermore, magnesium substitution results in a net global warming potential reduction only when using the most favorable assumptions on SF_6 use (Raugei et al. 2015).
- **Substitution characteristics.** The weight-to-weight ratio at which one metal is substituted for another would affect LCA results, as would any assumptions about metal stiffness and strength. One study estimated that the magnesium breakeven distance with steel can more than triple from approximately 70,000 kilometers (43,500 miles) to 240,000 kilometers (149,000 miles) depending on substitution ratios (Kelly et al. 2015).
- **Recycling**. Magnesium is considered well suited to recycling, with recovery rates in excess of 90 percent (Ehrenberger 2013), comparing favorably with recovery rates for steel and aluminum, which demonstrate lower recycling rates. Approximately 5 percent of the energy used in production of virgin materials is needed for remelting. Two types of materials are recycled: manufacturing scraps and post-consumer materials (Sivertsen et al. 2003). Emissions associated with repurposing magnesium from virgin materials are estimated to range from 20 to 47 kilograms (44 to 103 pounds) of CO_2e per kilogram of magnesium, while the emissions associated with recovering recycled magnesium from vehicle disposal are estimated to average 1.1 kilogram (2 pounds) CO_2e per

[20] SF_6 has a global warming potential of 23,500 according to the IPCC Fifth Assessment Report (AR5).

kilogram of magnesium (Ehrenberger 2013). Therefore, the degree of recycling can have a great impact on LCA results.

6.3.3 Vehicle Batteries

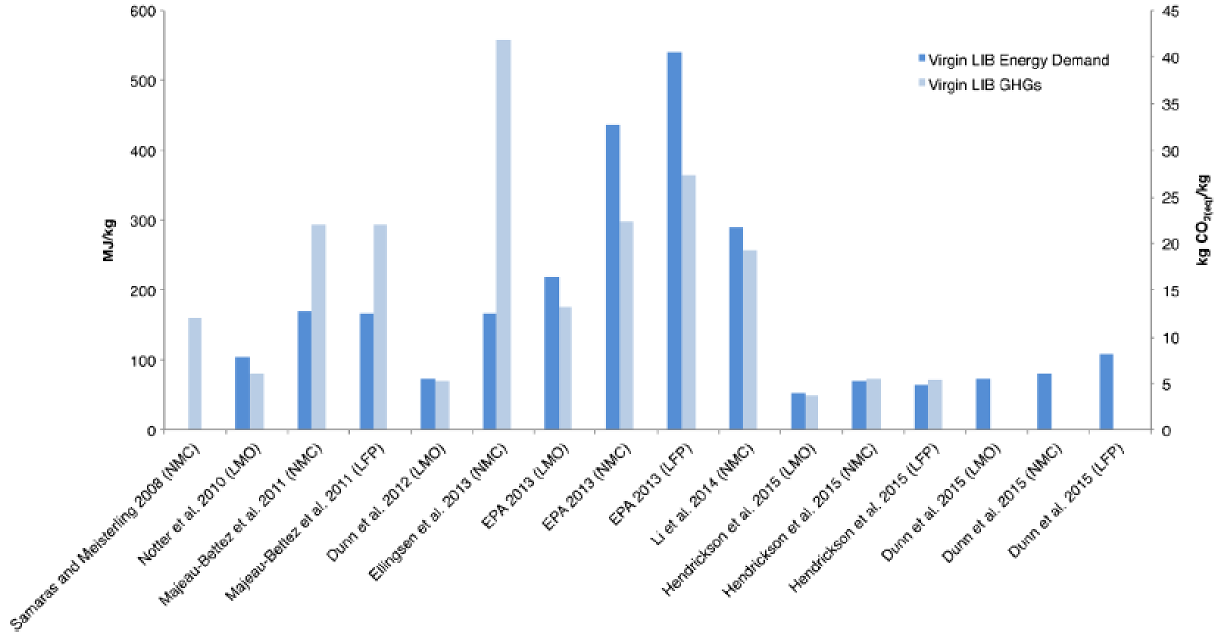
Historically, battery manufacturers for passenger cars and light trucks have used lead-acid chemistries for internal combustion engine vehicles. EV, PHEV, and HEV manufacturers have begun using new battery chemistries based on the results of research to increase energy storage capacity.

The lithium ion (Li-ion) battery is the preferred battery technology for EVs because of its electrochemical potential, lightweight properties, comparatively low maintenance requirements, and minimal self-discharge characteristics, the latter of which enables Li-ion batteries to stay charged longer (Notter et al. 2010). However, Li-ion batteries are an evolving technology. Researchers and manufacturers are continually developing new battery chemistries to increase energy density while reducing costs.

Li-ion batteries primarily consist of stacked battery cells. Cells represent the bulk of material weight, which includes the cathode, anode, binder, and electrolyte. Anodes typically are composed of graphite, and cathodes (active materials) can vary based on the specific battery chemistry used. LCA literature has focused on three cathode types: lithium manganese oxide, lithium iron phosphate, and lithium nickel manganese cobalt oxide (Nealer and Hendrickson 2015). Each cell is sealed in a casing, typically aluminum or steel. The stacked cells are combined with other components, including wiring and electronic parts for the battery management system (EPA 2013a).

The relative impact becomes greater when the vehicle is operated with a greater renewable-based grid mix (Dunn et al. 2015a). Estimates for the relative contribution of Li-ion batteries can vary significantly both between and within LCAs. Ranges in results are large, where studies have shown batteries can contribute 10 percent or less (Notter et al. 2010, EPA 2013a) or almost 25 percent of total GHG emissions (Dunn et al. 2015b, EPA 2013a, Hawkins et al. 2013). LCAs and LCA reviews have highlighted this, but focus on different drivers of results. One review focuses on LCA scope and vehicle lifetime assumptions (Hawkins et al. 2012), while another details battery design and specific LCA methods (Nealer and Hendrickson 2015). Detailed LCAs of EV Li-ion battery production highlight specific materials in results (Notter et al. 2010, EPA 2013a, Li et al. 2014), while others closely analyze battery manufacturing and assembly processes as drivers of impacts (Ellingsen et al. 2014, Dunn et al. 2015a). Figure 6.3.3-1 shows the variations in LCA Li-ion battery results for energy consumption and GHG emissions from a literature review (Nealer and Hendrickson 2015).

Figure 6.3.3-1. Greenhouse Gas Emissions and Energy Consumption of Electric Vehicle Lithium-Ion Battery Production (per kilogram of battery)



Source: Nealer and Hendrickson 2015
MJ/kg = megajoule per kilogram; kg $CO_{2(eq)}$/kg = kilograms of carbon dioxide equivalent per kilogram; LIB = lithium-ion battery; GHG = greenhouse gas

Lead-acid batteries (LABs) in internal combustion engine vehicles have negligible GHG emissions relative to the rest of the vehicle's life cycle (Hawkins et al. 2012, Samaras and Meisterling 2008). However, mishandling these batteries in disposal and end-of-life can lead to exposure to toxic and hazardous materials, specifically lead and sulfuric acid (Los Angeles County 2015, Kentucky Division of Waste Management 2017). Because of these risks, more than 40 states have some form of purchase fee, disposal requirement, or recycling requirement designed to address the end-of-life handling of LABs (BCI 2017).

In North America, the recycling rate for LABs is almost 100 percent, and recycled lead from LABs contributed to more than 85 percent of total U.S. lead production in 2011 (Commission for Environmental Cooperation 2013, USGS 2014). U.S. secondary lead from LABs is recycled through a smelting process and totaled almost 1.1 million metric tons in 2011. The United States exported more than 300,000 metric tons of lead contained in used LABs in 2011, where 67 percent of this went to Mexico and 25 percent to Canada (USGS 2014). Secondary lead recycling through smelting can generate toxic lead emissions, which are regulated by ambient air standards domestically. U.S. exports of LABs for secondary lead production have increased in recent years to countries with less stringent lead emission standards, primarily Mexico (Commission for Environmental Cooperation 2013).

EV Li-ion batteries pose significant environmental challenges in solid waste management, particularly for regions with aggressive recycling goals such as California and New York. Rapid expansion of EV adoption would create large battery waste flows for solid waste infrastructure not designed for reuse and recovery of Li-ion battery materials (Hendrickson et al. 2015). Recycling technologies are limited and evolving, and LCAs have focused on this aspect of the battery life cycle to better understand the potential adverse impacts (Dunn et al. 2012, EPA 2013a, Hendrickson et al. 2015).

LCAs of Li-ion battery recycling have focused on three recycling technologies: pyrometallurgy, hydrometallurgy, and physical processes (Dunn et al. 2012, EPA 2013a, Hendrickson et al. 2015). Pyrometallurgy uses a combination of smelting followed by leaching to recover slag and valuable metals. Hydrometallurgy uses chemical leaching, capable of recovering valuable metals and lithium. Physical processes offer advantages over the other two alternatives through lower energy use and higher recovery rates. Of the three, pyrometallurgy is currently most widely used (Nealer and Hendrickson 2015). All three options offer benefits in reduced life-cycle energy demands and avoided material waste flows, although estimates for total savings can vary significantly (5.0 to 70.5 megajoule per kilogram battery recovered) (Hendrickson et al. 2015).

Other end-of-life alternatives for EV batteries include reuse applications for energy storage. Currently, when EV batteries are removed from vehicle operation, significant battery capacity remains, although to an uncertain degree (Sathre et al. 2015). LCAs have analyzed the potential for renewable energy storage for these second life applications, and the estimated GHG emission reduction when substituted for fossil fuel electricity generation. Results are highly dependent on assumptions for battery performance in energy storage and grid mixes. However, when replacing fossil fuel generation with renewable sources, GHG emission reduction benefits can be significant both in reducing impacts in electricity generation and overall EV life-cycle emissions (Ahmadi et al. 2014, Faria et al. 2014, Sathre et al. 2015).

6.3.4 Vanadium Redox Flow Batteries

Vanadium redox flow batteries (VRFBs) are an emerging technology where energy is stored in the electrolyte, rather than a typical battery design (e.g., lead-acid, Li-ion, fuel cell) where a cathode discharges energy to supply power. VRFBs are attractive for EV use because of fast recharge rates relative to other battery designs. A VRFB design would only need to replenish electrolytes that have been charged off-site, whereas a typical battery design would take significantly longer to recharge the active material. VRFBs can also have long lifetimes, around 20 years, providing the potential for reduced life-cycle costs to consumers. However, VRFBs have a low-energy density, which could lead to increased weight and reduced efficiency and range of EVs (IDTechEx 2016). It is currently unclear whether VRFBs will be a commercially viable technology for EV batteries within the timeframe of the rule.

LCAs have assessed the associated GHG emissions with VRFB use in energy storage systems. While these studies do not specifically address VRFBs in EV applications, the studies analyze similar battery production methods and designs that could be adapted for vehicle use. One study analyzed the life-cycle GHG emissions associated with a wind-turbine energy storage system using VRFBs, finding that battery production and infrastructure emissions ranged from 18 to 21 g CO_2e/kWh of electricity produced, depending on the number of wind turbines used. The overall energy storage system emissions ranged from 92 to 437 g CO_2e/kWh, making the VRFB components about 4 to 23 percent of total system emissions (Arbabzadeh et al. 2015). Another study analyzed VRFBs used to store surplus wind electricity for multiple countries, which occurs at times when demand is too low to use a wind system's entire output. The authors found that battery-related products emitted 25 to 55 g CO_2e/kWh of surplus energy stored, varying by country (Sternberg et al. 2015).

6.3.5 Tires

Tires affect 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. Tires are continuously deformed while rolling by the weight of the vehicle, which causes energy to dissipate in the form of heat. As a result, the engine must consume additional fuel to overcome the rolling resistance of the tires when propelling the vehicle (NAS 2006). Tires consume about 20 to 30 percent of vehicle drivetrain net energy output, and improving the rolling resistance of replacement tires by 10 percent can reduce fuel consumption by 1 to 2 percent (ICCT 2011). Some tests have shown that a 30 percent reduction in rolling resistance results in a 5 percent reduction of fuel consumption (Saur et al. 1997). According to a life cycle analysis performed by Continental, 20.9 percent of a vehicle's fuel consumption can be attributed to tires, with 16 percent attributed specifically to rolling resistance (Continental 1999). Changes to the physical design of tires can reduce the energy needed to overcome rolling resistance, leading to reductions in fuel consumption.

Approximately 88 percent of all resources and 95 percent of the cumulative energy input consumed in the life of a tire are consumed in the use phase (Continental 1999, Boustani et al. 2010). Roughly 6.9 percent of resources are consumed in the process of extracting the raw materials, which include mostly silica, synthetic rubber, carbon black, and steel. Approximately 4.8 percent of resources is expended in the production phase of the tire and the remaining 0.2 percent is consumed in the transport phase (Continental 1999). Thus, the environmental impacts from the life cycle of a tire mostly occur because of fuel consumption during the use phase. By comparison, the impacts from production and end-of-life phases are less significant.

Vehicle rolling resistance is expected to decrease over time. The National Research Council (NRC 2013c) projected scenarios for reductions in light-duty new-vehicle fleet rolling resistance to 2030. In the midrange case, the authors projected a 26 percent decrease in rolling resistance for passenger cars and a 15 percent decrease in rolling resistance for light trucks (NRC 2013c).

One mechanism for lowering rolling resistance in tires is increasing the use of silica to replace carbon black (Lutsey et al. 2006), especially in combination with natural rubber. The properties of natural rubber contribute to lower rolling resistance but provide decreased traction compared to synthetic rubber. Losses in traction can be overcome with increased use of silica (Pike and Schneider 2013). Discussion in the NHTSA/EPA rulemaking support documents concluded that tire technologies that enable improvements of 10 and 20 percent have been in existence for many years (EPA and NHTSA 2012). Achieving improvements up to 20 percent involves optimizing and integrating multiple technologies, with a primary contributor being the adoption of a silica tread technology (NRC 2015).

According to Continental's LCA, substituting silica for carbon black filler leads to a reduction in the global warming potential of around 9.5 percent due to a drop in CO_2 and carbon monoxide of approximately 9.5 and 9.8 percent respectively, with a decrease of sulfur dioxide, NO_X, and ammonia released as well. Partially substituting silica for carbon black as filler can reduce the cumulative energy input over the entire life of the tire by up to 9.3 percent. In total, a reduction of approximately 8.7 percent in the consumption of resources is achieved, due to petroleum savings of approximately 9.8 percent (Continental 1999).

Another LCA compared a carbon black tire to a silica/silane tire (which has lower rolling resistance). The primary energy demand for the production of the carbon black tire was 197 megajoule and for the silica/silane tire was 84 megajoule. This corresponded to emissions of 9.2 kilograms (20 pounds) of CO_2 from the production phase of the carbon black tire and 6.0 kilograms (13 pounds) of CO_2 from the production phase of the silica/silane tire. Because of increases in the quantities of solid and liquid waste and of ash and slag, a silica tire would produce approximately 3.4 percent more waste than a carbon black tire. Additionally, production of filler silica increases the negative impact on wastewater

(Continental 1999). Given the limited availability of LCAs in recent literature, further research is needed to better quantify environmental impacts of low-rolling resistance tires across the entire life cycle.

NHTSA subjected five tire models to on-vehicle tread wear testing and found no clear relationship between tread wear and rolling resistance levels (NHTSA 2009). 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. Other anecdotal and qualitative sources indicate that production and use of tires designed to reduce rolling resistance may affect tire manufacturing energy, durability, and opportunities for retread. A reduction in durability and retread opportunities could decrease the effective life of the tires, creating more waste and requiring additional tire manufacturing; however, improving technologies for tire design and rubber compounds are reducing concerns over tread life with each new tire model (NACFE 2015).

6.3.6 Aerodynamics and Drag

Drag is a function of the frontal area of the vehicle, the density of the air, the coefficient of drag of the vehicle, and the vehicle speed squared. The relation between drag and speed shows that aerodynamics of vehicles have less impact at lower speeds but much greater effect at highway speeds (Pandian 2012). At low speeds (e.g., the EPA city driving cycle) about 25 percent of the energy delivered by the drivetrain is used to overcome aerodynamic drag; at high speeds, about 50 percent or more of the energy is used to overcome drag (NRC 2013c).

Argonne National Laboratory estimated that, without engine modifications, a 10 percent reduction in aerodynamic drag would result in about a 0.25 percent reduction in fuel consumption for the urban cycle and a 2.15 percent reduction for the highway cycle (NRC 2015). Under average driving conditions, a 10 percent reduction in drag resistance will reduce fuel consumption by about 2 percent. The coefficient of drag is a figure that measures the force of air drag resistance on an object, such as a car, where the lower the drag coefficient, the more aerodynamic the vehicle.

Vehicle drag can be reduced with more aerodynamic vehicle shapes, smoothing the underbody, wheel covers, active cooling aperture control (radiator shutters), and active ride height reduction (NRC 2013c). Reducing the height and width of the car can reduce the frontal area, but there is a limit to how small this area can be while still allowing people to sit comfortably inside the vehicle. Designers can change specific aspects of the shape of the body of the vehicle to reduce the total aerodynamic drag and increase fuel economy (Pandian 2012). Reducing the size of the separation zone, which is the area behind the car containing the vortices behind the car, is another predominant method of decreasing aerodynamic drag and can be done by slightly tapering the rear end of a car (Pandian 2012).

Another large source of drag is the underside of the vehicle and the wheel wells. Drag from air that flows through the gaps between the wheels and the body of the car can contribute to up to one sixth of the total drag on the vehicle. Wheel skirts can be attached to the rear wheels of a car and underside paneling can be used to prevent air from being caught in mechanical devices under the car (Pandian 2012).

The *Assessment of Fuel Economy Technologies for Light Duty Vehicles* 2015 report determined that, to achieve a 10 percent reduction in aerodynamic drag, vehicles would require significant changes, including wind deflectors (spoilers) and possibly the elimination of side view mirrors (NRC 2015). While vehicles with higher drag coefficients (e.g., trucks, vans, and boxlike vehicles) can reduce drag, vehicle functionality could be diminished. If vehicle functionality (including curbside appeal) is compromised, then the vehicle's appeal to the consumer would be reduced (NRC 2015).

Average reductions in new-vehicle-fleet aerodynamic drag resistance for the midrange case are estimated as 21 percent in 2030, leading to a 4 percent reduction in fuel consumption. The midrange case also estimated a 35 percent average reduction in new-vehicle-fleet aerodynamic drag in 2050, leading to a 7 percent reduction in fuel consumption (NRC 2013c).

Additional research is needed to determine the life-cycle impacts of applying aerodynamic technologies. 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. Most of the available scientific literature is focused on technologies for reductions in aerodynamic drag for trucking fleet tractors and trailers.

6.4 Conclusions

The information in this chapter helps the decision-maker 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 phases beyond the vehicle use phase. The overarching conclusion based on this synthesis of the LCA literature is that most material and technology options would 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 Sources

The LCA literature synthesis revealed qualitative information about upstream natural gas, petroleum, and electricity emissions to supplement the analyses in Chapter 4, *Air Quality,* and Chapter 5, *Greenhouse Gas Emissions and Climate Change*. In general, the LCA literature synthesis found that upstream emissions make up less than 20 percent of total life-cycle GHG emissions and less than 20 percent of total non-GHG emissions. The following tentative findings emerged from the LCA literature synthesis related to vehicle energy production and use:

- **Fuel source.** Gasoline remains the primary automotive fuel source. Recent passenger car and light truck sales and use projections predict that gasoline will continue to be the main fuel source, but alternative fuel source consumption, namely electricity for EVs and biofuels, will rapidly increase in the coming decades. There is significant variation in how these projections analyze future EV adoption rates.
- **Hydraulic fracturing.** Gasoline and natural gas domestic resources have become more dependent on hydraulic fracturing of shale formations. These sources, especially shale gas, have been shown to have similar or higher life-cycle GHG emissions compared to conventional sources, although results can vary based on study assumptions and scopes. Hydraulic fracturing has also been linked with increased water pollution.
- **Renewable energy.** Electricity will decline in carbon intensity if renewable energy and natural gas replace existing coal power.

- **Charging location and timing.** EVs can offer significant life-cycle GHG emission savings over conventional passenger cars and light trucks, but this is highly dependent on the location of charge. EVs from regions with high portions of coal electricity (i.e., the Midwest) often have life-cycle impacts similar to conventional vehicles. EV emissions can be influenced by when operators choose to charge their vehicles (i.e., during times of peak use or during low demand), but results vary considerably between energy utilities.
- **Biofuel.** Recent research on land use change impacts and upgrades to production facility efficiency have reduced estimates of life-cycle GHG emissions from biofuels, especially for ethanol. Continued improvements to production could further reduce emissions with respect to conventional vehicles.

6.4.2 Materials and Technologies

The magnitude of life-cycle impacts associated with materials and technologies is small in comparison with the emissions reductions from avoided fuel consumption during vehicle use. The LCA literature synthesis revealed the following trends for materials and technologies:

- **Light-weight materials.** Light-weight materials manufactured using aluminum, high-strength steel, composites, and magnesium require more energy to produce than similar conventional steel components.
- **Weight-reducing technologies.** Weight-reducing manufacturing—such as hydroforming, laser welding, and aluminum casting—requires new equipment to produce passenger cars and light trucks.
- **Net environmental benefits of materials and technologies.** Upstream energy requirements for the manufacture of light-weight materials are small relative to efficiencies achieved. Although the production of weight-reducing materials requires more upstream energy, the operating efficiencies gained can be significant, leading to a net decrease in environmental impacts and in GHG emissions.
- **Lithium-ion batteries.** Lithium-ion batteries have become the standard in EV designs, but active-material chemistries continue to evolve. The contribution of these batteries to the overall life cycle varies considerably between studies. Emerging research has focused on battery recycling technologies, as new processes are being developed to mitigate concerns over increasing solid waste flows.
- **Aerodynamic design.** There are performance trade-offs associated with aerodynamic features and low-rolling resistance tires. Aerodynamic features add weight and have associated upstream energy requirements.
- **Further LCA research.** Scientific understanding of aerodynamic features, low-rolling resistance tires, and other technologies is still evolving. More research is needed to assess impacts upstream and downstream of these products.

CHAPTER 7 OTHER IMPACTS

This chapter describes the affected environment and environmental consequences of the Proposed Action and alternatives on resources other than those described in Chapter 3, *Energy*, Chapter 4, *Air Quality*, and Chapter 5, *Greenhouse Gas Emissions and Climate Change*. These additional resources are described in the following sections: Section 7.1, *Land Use and Development*, Section 7.2, *Hazardous Materials and Regulated Waste*, Section 7.3, *Historical and Cultural Resources*, Section 7.4, *Noise*, and Section 7.5, *Environmental Justice*. With respect to each of these issues, because the magnitude of the changes that the Proposed Action and alternatives 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 No Action Alternative. In addition, many of the impacts of the Proposed Action and alternatives discussed in the following sections have a considerable degree of variability and uncertainty given that manufacturers have flexibility to choose how they will comply with the proposed standards.

In this EIS, NHTSA has not analyzed some resource areas traditionally discussed in DOT EISs because the action alternatives would have negligible or no impact on these resource areas or because they are discussed in other documents that are available for public review and comment. These resource areas are as follows:

- **Safety Impacts on Human Health.** In developing the proposed standards, NHTSA analyzed how future changes in fuel economy might affect human health and welfare through vehicle safety performance and the rate of traffic fatalities. To estimate the possible safety impacts of the proposed standards, NHTSA analyzed impacts from mass reduction, fleet turnover, and the rebound effect. NHTSA used statistical analyses of historical crash data and an engineering approach to investigate the cost and feasibility of mass reduction of vehicles while maintaining safety and other desirable qualities. NHTSA also examined the safety impacts that would result from delayed purchases of safer, newer model year vehicles due to higher vehicle prices resulting from CAFE. Finally, NHTSA examined the impact on vehicle miles traveled (VMT) due to changes in the cost of driving, also known as the rebound effect. These effects are discussed in Chapter 11 of the Preliminary Regulatory Impact Analysis (PRIA).
- **Endangered Species Act (ESA).** Pursuant to Section 7(a)(2) of the Endangered Species Act,[1] NHTSA incorporates by reference its response to a public comment on this issue in the MY 2017–2025 CAFE Standards Final EIS (NHTSA 2012: 9-101). For that rulemaking, NHTSA concluded that a Section 7(a)(2) consultation was not required because any potential for a specific impact on 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 increases anticipated to occur under the Proposed Action and alternatives.
- **Section 4(f).** Title 49 U.S.C. Section 303 (Section 4(f)) limits the ability of DOT agencies to approve the use of land from publicly owned parks, recreational areas, wildlife and waterfowl refuges, or public and private historic sites unless certain conditions apply. Because the action alternatives are not a transportation program or project requiring the use of Section 4(f) properties, a Section 4(f) evaluation has not been prepared.

[1] 16 U.S.C. § 1536(a)(2).

7.1 Land Use and Development

7.1.1 Affected Environment

Land use and development refer to human activities that alter land (e.g., industrial and residential construction or clearing of natural habitat for agricultural or industrial use). This section discusses changes in mining practices, agricultural practices, and development land use patterns that may occur as a result of the Proposed Action and alternatives.

7.1.2 Environmental Consequences

Shifts toward or away from more efficient, lighter vehicles, either because of consumer preference for fuel-efficient vehicles or manufacturers' decisions to reduce or increase vehicle mass, could result in changes in mining land use patterns. Mining for the minerals needed to construct lighter vehicles (primarily aluminum and magnesium) could shift some metal-extraction activities to areas rich in these resources. Tonn et al. (2003) note that such a shift in materials "could reduce mining for iron ore in the United States, but increase the mining of bauxite [aluminum ore], magnesium, titanium, and other materials in such major countries as Canada, China, and Russia, and in many small, developing countries, such as Guinea, Jamaica, and Sierra Leone." Relocating mining to new sites for these alternative resources could result in environmental impacts, such as destruction of natural habitat from altered land cover. In contrast, a shift away from lighter-weight vehicles would not require new sites for these resources and would not involve the potential environmental impacts associated with the relocation of mining sites. Under the Proposed Action and alternatives, as well as the No Action Alternative, a shift toward or away from lighter-weight materials is possible. Because the No Action Alternative is the most stringent of the alternatives, it is likely that lighter-weight materials would be used under this alternative, potentially leading to new mining sites, as discussed. Because the Proposed Action and alternatives are less stringent than the No Action Alternative, shifts toward lighter vehicles and the associated new mining activities seem less likely, but still possible, under these alternatives.

The Proposed Action and alternatives are not anticipated to affect the production or use of biofuel technology in MY 2021–2026 light-duty vehicles in any predictable way. Depending on how manufacturers chose to comply with the standards, an increase or decrease in biofuel production and use is possible. The current production of ethanol is affected primarily by the EPA renewable fuel standard program, a separate program that establishes targets for several categories of renewable fuels consumption. The most recent standard issued (for 2018) caps the renewable fuel target at more than 19 billion gallons per year. Because the alternatives are not expected to affect the use or production of renewable fuels in any predictable way, NHTSA does not anticipate distinguishable land use impacts related to biofuel production.

By increasing fuel costs per mile, lower fuel economy standards under the Proposed Action and alternatives could provide an incentive for decreased driving, which could lead to lower vehicle miles traveled (VMT). In areas where the highway network, infrastructure availability, and housing market conditions allow, this could decrease demand for low-density residential development beyond existing developed areas and increase demand for residences in more densely populated areas that are less dependent on automobiles for travel and are associated with lower VMT per household (FHWA 2014, DOT 2016c). Many agencies are implementing measures, such as funding smart-growth policies, to influence settlement patterns to reduce VMT and fuel use to meet climate change goals (Moore et al.

2010, EPA 2017a). See Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, for more information regarding VMT.

Under the Proposed Action and alternatives, fuel consumption is anticipated to increase compared to the No Action Alternative, with increases ranging from a total of 206 billion GGE (gasoline gallon equivalents) under Alternative 1 to 56 billion GGE under Alternative 7 from 2020 to 2050 (Chapter 3, *Energy*). This represents a 2 to 7 percent increase in aggregate fuel consumption compared to the No Action Alternative. This increase in fuel consumption is likely to result in additional oil extraction and refining, along with a potential need for new pipelines. To the extent that existing oil extraction and refining sites could not accommodate the production increase, some former land uses may be converted. The establishment of new pipelines, if necessary, would also affect land use falling in the right-of-way of existing or proposed pipeline routes. Because the Proposed Action and alternatives represent a small percentage of increased fuel consumption over a long period, however, impacts on land use are likely to be minimal.

7.2 Hazardous Materials and Regulated Waste

7.2.1 Affected Environment

Hazardous waste is defined 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 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 Proposed 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. This section focuses on the greatest sources of and environmental impacts from hazardous materials and regulated wastes. Chapter 6, *Life-Cycle Impact Assessment of Vehicle Energy, Materials, and Technologies*, also examines life-cycle environmental impacts—primarily energy demands and GHG emissions—of electric vehicle-related hazardous materials (e.g., lithium-ion [Li-ion] batteries) and waste management practices. For hazardous waste impacts associated with electric vehicle-related hazardous materials, see Section 6.2.3, *Electric Vehicles*, and Section 6.3.3, *Vehicle Batteries*.

Hazardous waste produced from oil and gas extraction and refining can present a threat to human and environmental health. Onshore environmental impacts are most commonly caused by the improper disposal of saline water 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, Pichtel 2016). 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 2017d).

The development of new techniques, such as hydraulic fracturing, has opened vast new energy reserves in the United States. Hydraulic fracturing provides approximately two-thirds of U.S. natural gas production (EIA 2016b) and half of U.S. oil production (EIA 2016d). Oil supplies contained in low-permeability rocks, such as shale, can be accessed with hydraulic fracturing (EIA 2017e). Increased use of hydraulic fracturing introduces new potential environmental impacts on U.S. drinking water. The extraction of natural gas from shale can affect drinking water quality because of gas migration, contaminant transport through fractures, wastewater discharge, and accidental spills (Vidic et al. 2013, EPA 2016g).

In 2016, EPA published a final report on *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States*. EPA found scientific evidence that hydraulic fracturing activities can affect drinking water resources under some circumstances. EPA identified certain conditions under which impacts from hydraulic fracturing activities could be more frequent or severe, such as water withdrawals in times or areas of low water availability, spills that result in large volumes or high concentrations of chemicals, problems with hydraulic fracturing fluid injections, discharges of inadequately treated wastewater to surface water, and disposal of wastewater in unlined pits (EPA 2016h). A recent study analyzed the toxicity of certain chemicals in wastewater produced from hydraulic fracturing and found that, of 240 chemicals analyzed, 157 were associated with either developmental or reproductive toxicity (Elliott et al. 2016). The authors further noted that 67 of these chemicals were of particular concern because they had an existing federal health-based standard or guideline, although it was not determined whether levels of chemicals exceeded the guidelines. Hydraulic fracturing has also been shown to potentially induce earthquakes in Canada (Bao and Eaton 2016), although the U.S. Geological Survey attributes induced earthquakes in the United States to wastewater disposal (USGS 2017).

Offshore environmental impacts from oil and gas extraction can result from the release of improperly treated produced water into the water surrounding an oil platform (EPA 1999b, Bakke et al. 2013, OSPAR Commission 2014). Offshore platform spills, although rare,[2] can have devastating environmental impacts. According to the American Petroleum Institute, oil and gas production generate more than 18 billion barrels of waste fluids, including produced water and associated waste, annually in the United States (EPA 2012e, 2016j).

The oil extraction process used to produce motor vehicle fuel 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 with adverse impacts on water resources, plants, animals, and cultural resources. Oil extraction activities could also affect biological resources through habitat destruction and encroachment.

7.2.2 Environmental Consequences

The projected increase in fuel production and combustion resulting from the Proposed Action and alternatives (Section 3.4, *Environmental Consequences*) could lead to an increase in petroleum extraction and refining for the transportation sector compared to the No Action Alternative. 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 1995a). EPA defines a release as the “on-site discharge of a toxic chemical to the environment…emissions to the air, discharges to bodies of water, releases at the facility to land, as well as contained disposal into underground injection wells” (EPA

[2] Historically, there were six spills per 100 billion barrels of oil produced from offshore oil platforms between 1964 and 2010 (Anderson et al. 2012).

1995a, EPA 2016g). Some of the most common toxic substances released by the petroleum refining industry are volatile chemicals (highly reactive substances that are prone to state changes or combustion, including benzene, toluene, ethylbenzene, xylene, cyclohexane, ethylbenzene, and 1,2,4-trimethylbenzene) (EPA 1995a, EPA 2003a). These substances are present in crude oil and finished petroleum products. Other potentially dangerous substances commonly released during the refining process include ammonia, gasoline additives (methanol, ethanol, and methyl tert-butyl ether), chemical feedstocks (propylene, ethylene, and naphthalene), benzene, toluene, ethylbenzene, xylene, and n-hexane (EPA 2014g).[3] Spent sulfuric acid is by far the most commonly produced toxic substance; however, it is generally reclaimed rather than being released or transferred for disposal (EPA 1995a). EPA promulgated a rule in 2015 requiring refiners to reduce toxic air pollutants by 53,000 tons annually, representing a 59 percent reduction from current levels.[4] Because oil and gas extraction and refining are expected to increase under the Proposed Action and alternatives, associated emissions of volatile chemicals and other potentially dangerous substances are expected to increase as well, compared to the No Action Alternative. See Chapter 4, *Air Quality*, for an in-depth discussion of the health impacts of hazardous air pollutants.

Spills of oil or other hazardous materials during oil and gas extraction and refining can also lead to surface water and groundwater contamination and result in impacts on drinking water and marine and freshwater ecosystems. Because the Proposed Action and alternatives have the potential to increase overall petroleum extraction and refining levels due to decreased fuel efficiency, the total number of hazardous material spills that result from extraction and refining may increase compared to the No Action Alternative.

Oil exploration and extraction also result in intrusions into onshore and offshore natural habitats and can involve construction within natural habitats. Ecosystems that experience encroachment may have significant effects from drilling on benthic (bottom-dwelling) populations, migratory bird populations, and marine mammals (Borasin et al. 2002, USFWS 2009, NOAA 2012, Bakke 2013). The increase in oil and gas extraction and refining that could occur under the Proposed Action and alternatives is also likely to result in an increase in these types of impacts on natural habitats compared to the No Action Alternative.

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, 2017b). Declines in the biodiversity of aquatic species

[3] 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 interdependent; therefore, changes in pH or aluminum levels can severely affect biodiversity (EPA 2017b). 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 short-term eye and skin irritation as well as blood disorders, reproductive and developmental disorders, and cancer (EPA 2017b). Long-term exposure to toluene emissions 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 exposure could cause blood disorders (EPA 2017b). 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. 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 2017b).

[4] 40 CFR Parts 60 and 63.

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, EPA 2017b). The potential increase in fuel production and combustion resulting from the Proposed Action and alternatives could increase pollutant emissions that cause acid deposition, compared to those emissions under the No Action Alternative.

Motor vehicles, the motor vehicle equipment industry, and businesses engaged in the manufacture and assembly of cars and trucks produce hazardous materials and toxic substances. EPA reports that solvents (e.g., xylene, methyl ethyl ketone, acetone) are the most commonly released toxic substances of those that the agency tracks for this industry (EPA 1995a). These solvents are used to clean metal and are used in the vehicle finishing process during assembly and painting (EPA 1995a). Other wastes from the motor vehicle equipment industry include 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).

To comply with the proposed standards, some manufacturers could choose to substitute lighter-weight materials (e.g., aluminum, high-strength steel, magnesium, titanium, or plastic) for conventional vehicle materials (e.g., conventional steel and iron). This could increase the total waste stream from automobile manufacturing, as well as waste streams resulting from mining and other production wastes. See Section 6.3.1, *Vehicle Mass Reduction by Manufacturing Technologies,* and Section 6.3.2, *Vehicle Mass Reduction by Material Substitution*, for a discussion of the environmental impacts associated with the use of lighter-weight materials in vehicles. Manufacturers could also incorporate a number of technologies for electrification to comply with the proposed standards, including hybrid electric vehicles (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). See Section 6.2.3, *Electric Vehicles*, and Section 6.3.3, *Vehicle Batteries*, for a discussion of the environmental impacts associated with the use of vehicle electrification.

In summary, the potential increase in fuel production and consumption under the Proposed Action and alternatives could lead to an increase in the amount of hazardous materials and waste created by the oil extraction and refining industries compared to the No Action Alternative. NHTSA expects corresponding increases in the associated environmental and health impacts of these substances. The Proposed Action and alternatives could also lead to the decreased use of some lighter-weight materials and advanced technologies, depending on the mix of methods the manufacturers use to meet the fuel efficiency standards, economic demands from consumers and other manufacturers, and technological developments. Because there is still substantial uncertainty regarding how manufacturers would choose to comply with the standards, including whether they would use lighter-weight materials and other technological developments associated with electric vehicles, this EIS does not quantify impacts related to waste produced during the refining process due to mass reduction or wastes associated with electric vehicle production and use. See Chapter 6, *Life-Cycle Impact Assessment of Vehicle Energy, Materials, and Technologies*, for a discussion of the environmental impacts associated with down-weighting and electric vehicle technologies.

7.3 Historical and Cultural Resources

7.3.1 Affected Environment

Section 106 of the National Historic Preservation Act of 1966[5] and its implementing regulations[6] state that agencies of the Federal Government must take into account the impacts of their actions on historical 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. Historical 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.

Because the Proposed Action and alternatives do not have the potential to cause significant impacts on historical properties, NHTSA has no further obligations under the Section 106 process.[7] The analysis in this section is intended to provide additional information in order to disclose impacts under NEPA.

7.3.2 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 dry deposition of pollution (EPA 2017b). Deposition of dry acidic compounds found in acid rain can also dirty historical buildings and structures, causing visual impacts and increased maintenance costs (EPA 2017b. EPA established the Acid Rain Program under Title IV of the 1990 Clean Air Act Amendments in 1995 requiring major emissions reductions of sulfur dioxide and NO_X from electric generating units (EPA 1995a).

The potential increase in fuel production and combustion under the Proposed Action and alternatives could lead to an increase in pollutant emissions that cause acid deposition compared to the No Action Alternative. An increase in the emissions of such pollutants could result in a corresponding increase in damage to historical and other structures caused by acid deposition. In terms of specific pollutant emissions, however, total NO_X emissions are anticipated to decrease slightly under the Proposed Action and alternatives compared to the No Action Alternative, except under Alternative 8, which would result in a slight increase in NO_X emissions (Chapter 4, *Air Quality*, Table 4.2.1-2). Moreover, downstream (tailpipe) emissions of both NO_X and sulfur dioxide are projected to decrease, while upstream (refinery and power plant) emissions of these pollutants are projected to increase. This means that the impacts of the Proposed Action and alternatives would differ by location across the country. However, because acid deposition can travel long distances in the atmosphere, the specific location of impacts is difficult to predict. In general, impacts under the Proposed Action and alternatives are not quantifiable because it is not possible to distinguish between acid deposition deterioration impacts and natural weathering (rain, wind, temperature, and humidity) impacts on historical buildings and structures and the varying impact of a specific geographic location on any particular historical resource (Striegel et al. 2003).

[5] 54 U.S.C. § 100101 et seq. (codified in 2014).

[6] 36 CFR Part 800.

[7] "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).

7.4 Noise

7.4.1 Affected Environment

Vehicle noise is composed primarily of the interaction between the engine/drivetrain, tire/road surface, and vehicle aerodynamics. Vehicle aerodynamic noise levels are generally low at typical roadway speeds. Tire/road surface noise increases with increasing vehicle speed. 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 estimated that 19.3 million people were exposed to day-night average sound levels of 65 decibels (EPA 1981). At a day-night average sound level of 65, 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 traffic noise measurements, noise levels for automobiles traveling at speeds of 50 miles per hour are between 70 and 75 A-weighted decibels[8] (measured 50 feet from the vehicles) (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, abrupt vehicle features that increase aerodynamic drag also contribute to noise. However, at typical highway speeds, aerodynamic noise is low—in terms of impacts on people adjacent to highways—compared to tire and engine/drive train noise. To reduce wind noise, some vehicle features can be redesigned to lower 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 is one of the primary causes of noise disturbance in homes (Ouis 2001, Theebe 2004, Henshaw 2016). Excessive amounts of noise can disturb and affect human health at certain levels. Potential health hazards related to noise range from annoyance (sleep disturbance, lack of concentration, and stress), to headaches and migraines, to hearing loss at high levels (Passchier-Vermeer and Passchier 2000, Henshaw 2016). Primary sources of noise in the United States include road and rail traffic, air transportation, and occupational and industrial activities. Noise generated by vehicles can cause 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 impact 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 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).

[8] A-weighted decibels, commonly used to describe environmental noise, express the relative loudness of sound to the human ear.

7.4.2 Environmental Consequences

Less fuel-efficient vehicles could decrease VMT, resulting in potential decreases in vehicle road noise. In general, noise levels from 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.

The Proposed Action and alternatives could lead to an increase or decrease 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. Less stringent alternatives would be associated with decreased use of hybrid technologies. A reduced percentage of hybrid technologies under the Proposed Action and alternatives could result in increased road noise, potentially offsetting some of the decrease in road noise predicted to result from decreased VMT compared to the No Action Alternative. In addition, noise reductions associated with the use of hybrid technologies could be offset at low speeds by manufacturer installation of pedestrian safety-alert sounds, as required by NHTSA (NHTSA 2016b).

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. CEQ has provided agencies with general guidance on how to meet the requirements of the EO as it relates to NEPA (CEQ 1997).

U.S. Department of Transportation (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. DOT also recently 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 2016b).

[9] Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-income Populations, 59 FR 7629 (Feb. 16, 1994).

[10] Department of Transportation Updated Environmental Justice Order 5610.2(A), 77 FR 27534 (May 10, 2012).

7.5.1 Affected Environment

The affected environment for environmental justice is nationwide, with a focus on areas that could contain low-income and minority communities who would most likely 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 near roadways, coastal flood-prone areas, and urban areas that are subject to the heat island effect.[11]

There is evidence that proximity to oil refineries could 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 impacts, among other possible impacts (HEI 2010, Heinrich and Wichmann 2004, Salam et al. 2008, Samet 2007, Adar and Kaufman 2007, Wilker et al. 2013, Hart et al. 2013). Climate change affects overall global temperatures, which could, in turn, affect the number and severity of outbreaks of vector-borne illnesses (GCRP 2014, 2016). Chapter 3, *Energy*, Chapter 4, *Air Quality*, Chapter 5, *Greenhouse Gas Emissions and Climate Change*, and Chapter 8, *Cumulative Impacts*, 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 could be more exposed or vulnerable to such effects.

Studies have found mixed evidence regarding a correlation between proximity to oil refineries and the prevalence of low-income and minority populations (Fischbeck et al. 2006, UCC 2007) or have cited anecdotal evidence (O'Rourke and Connolly 2003, Kay and Katz 2012). 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). 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. Therefore, disproportionate impacts on minority and low-income populations due to proximity to oil refineries are not predicted.

Studies have more consistently demonstrated a disproportionate prevalence of minority and low-income populations living near mobile sources of pollutants. In certain locations in the United States, for example, there is consistent evidence that populations or schools near roadways typically include a greater percentage of minority or low-income residents (Green et al. 2004, Wu and Batterman 2006, Chakraborty and Zandbergen 2007, Depro and Timmins 2008, Marshall 2008, Su et al. 2010, Su et al. 2011). These studies demonstrate trends in specific locations in the United States that may be indicative of broader national trends. Fewer studies have been conducted at the national level, yet those that do exist also demonstrate a correlation between low-income and minority status and proximity to roadways (Tian et al. 2013, Boehmer et al. 2013, Rowangould 2013, Kingsley et al. 2014). 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

[11] The heat island effect refers to developed areas having higher temperatures than surrounding rural areas. See Section 8.6.5.2, *Urban Areas*, for further discussion of the heat island effect.

[12] Public schools were determined to serve predominantly underprivileged students 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.

within 250 meters of a major roadway. Overall, these studies demonstrate a potential for disproportionate impacts on minority and low-income populations in proximity to roadways.

Some areas 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 nonurban 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, EPA 2017f). 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, 2014).

Independent of their proximity to pollution sources or climate change, locations of potentially high impact, low-income and minority populations could 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, 2013, 2017). In addition, increases in heat-related morbidity and mortality because of higher overall and extreme temperatures are likely to affect minority and low-income populations disproportionately, partially because 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 potential increase in fuel production and consumption projected as a result of the Proposed Action and alternatives compared to the No Action Alternative could lead to an increase in upstream emissions of criteria and toxic air pollutants due to increased extraction, refining, and transportation of fuel. As shown in Table 4.2.1-2 and Table 4.2.2-2, total emissions of criteria and toxic air pollutants are projected to remain constant or increase under all action alternatives compared to the No Action Alternative. To the extent that minority and low-income populations live closer to oil-refining facilities, these populations may be more likely to be adversely affected by the Proposed Action and alternatives. However, as noted, a correlation between proximity to oil refineries and the prevalence of low-income and minority populations has not been established in the scientific literature. Therefore, disproportionate impacts on minority and low-income populations due to their proximity to oil refineries are not foreseeable. In addition, the magnitude of the change in emissions relative to the baseline is very minor and would not be characterized as high and adverse.

As is shown in Table 4.2.1-2 and Table 4.2.2-2, downstream (tailpipe) emissions of criteria and toxic air pollutants for cars and trucks would decrease under all action alternatives compared to the No Action Alternative. This reduction in tailpipe emissions would reduce exposure of minority and low-income populations that reside near roads—and minority and underprivileged children that attend schools near major roadways—to criteria and toxic air pollutants. The result would be a net benefit to minority and low-income populations proximate to roadways in terms of reduced exposure to tailpipe emissions compared to the No Action Alternative. Because these anticipated impacts would in fact be beneficial, no disproportionate adverse impacts on minority and low-income populations due to their proximity to roadways are foreseeable.

As described in Chapter 5*, Greenhouse Gas Emissions and Climate Change*, the Proposed Action and alternatives would increase CO_2 emissions from passenger cars and light trucks by 2 to 10 percent, compared to the No Action Alternative (Table 5.4.1-1). Impacts of climate change could disproportionately affect minority and low-income populations in urban areas that are subject to the most substantial temperature increases from climate change. These impacts are largely because of the urban heat island effect. Additionally, minority and low-income populations that live in flood-prone coastal areas could be disproportionately affected. However, the contribution of the Proposed Action and alternatives to climate change impacts would be very minor rather than high and adverse. Compared to the annual 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 Proposed Action and alternatives would increase annual U.S. CO_2 emissions by 0.3 to 1.3 percent in 2100. Compared to annual global CO_2 emissions, the Proposed Action and alternatives would represent an even smaller percentage increase and would ultimately result in percentage increases in global mean surface temperature, atmospheric CO_2 concentrations, sea level, and ocean pH ranging from 0.06 percent to less than 0.001 percent (Table 5.4.2-2). These changes would be very small and incremental compared to the expected changes associated with the emissions trajectories in the GCAM Reference scenario.

Adverse health impacts would increase nationwide under each of the action alternatives compared to the No Action Alternative (Table 4.2.3-1). Although a number of the action alternatives would result in various criteria pollutant and air toxic decreases, emissions of PM2.5, DPM, and SO_X, in particular, would increase under all of the action alternatives, thus resulting in the anticipated adverse health impacts. Increases in these pollutant emissions, however, would be primarily the result of increases in upstream emissions (emissions near refineries and power plants), while downstream emissions (tailpipe emissions near roadways) are anticipated to decrease. Thus, as discussed previously, those minority and low-income populations that live close to roadways would experience beneficial health impacts under the Proposed Action and alternatives due to decreases in downstream emissions.

Independent of their proximity to pollution sources or climate change locations of potentially high impact, low-income and minority populations could be more vulnerable to the health impacts of pollutants and climate change. This is because minority and low-income populations tend to have less access to health care and tend to receive a lower quality of care. The increases in adverse health impacts under the action alternatives compared to the No Action Alternative would range from 0.3 percent (under Alternative 8 in 2025) to 5.2 percent (under Alternative 1 in 2050). These increases would be incremental in magnitude and would not be characterized as high.

Based on the foregoing, NHTSA has determined that the Proposed Action and alternatives would not result in disproportionately high and adverse human health or environmental effects on minority or low-income populations. The proposed rule would set standards nationwide, and although minority and low-income populations may experience some disproportionate effects, impacts of the Proposed Action and alternatives on human health and the environment would not be high and adverse.

CHAPTER 8 CUMULATIVE IMPACTS

8.1 Introduction

Under the CEQ NEPA implementing regulations, when preparing an environmental impact statement (EIS), NHTSA must consider the direct and indirect effects, as well as the cumulative impacts, of the Proposed Action and alternatives. CEQ defines direct effects as impacts "which are caused by the action and occur at the same time and place."[1] By contrast, indirect effects are impacts "which are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable."[2] A cumulative impact is defined 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. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time."[3] The purpose of analyzing cumulative impacts is to ensure that federal decision-makers consider the full range of consequences of the Proposed Action and alternatives within the context of other actions, regardless of what agency or person undertakes them, over time.

Section 8.2, *Methods*, outlines NHTSA's approach to defining the scope for the cumulative impact analysis and identifying the relevant past, present, and reasonably foreseeable actions that contribute to cumulative impacts. The following sections focus on cumulative effects in key impact areas analyzed in the EIS: Section 8.3, *Energy*; Section 8.4, *Air Quality*; Section 8.5, *Other Impacts*; and Section 8.6, *Greenhouse Gas Emissions and Climate Change.*

8.2 Methods

This section describes NHTSA's approach to defining the temporal and geographic scope of the cumulative impact analysis and to identifying other past, present, and reasonably foreseeable future actions.

8.2.1 Temporal and Geographic Scope of Analysis

The timeframe for this analysis of cumulative impacts extends from 2020 through 2050 for energy, air quality, and other impacts, and through 2100 for greenhouse gas (GHG) and climate impacts. As noted in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, the inherently long-term nature of the impacts of increasing GHG accumulations on global climate requires that GHG emissions for the Proposed Action and alternatives be estimated over a longer period than other environmental impacts. The geographic focus of this analysis for energy use and air quality impacts is national in scope while the analysis of climate impacts is global in scope, because GHG emissions in the United States may cause impacts around the world. This temporal and geographic focus is consistent with the analysis of direct and indirect impacts in Chapter 3, *Energy*, Chapter 4, *Air Quality*, Chapter 5, *Greenhouse Gas Emissions and Climate Change*, and Chapter 7, *Other Impacts*. This focus and the impact analysis are based on the reasonable ability of NHTSA to model or describe fuel consumption and emissions for the light-duty vehicle sector.

[1] 40 CFR § 1508.8(a).

[2] 40 CFR § 1508.8(b).

[3] 40 CFR § 1508.7.

8.2.2 Identifying Past, Present, and Reasonably Foreseeable Future Actions

The cumulative impact analysis evaluates the impact of the Proposed Action and alternatives in combination with other past, present, and reasonably foreseeable future actions that affect the same resources. The range of actions considered includes other actions that have impacts that add to, or offset, the anticipated impacts of the proposed fuel economy standards on resources analyzed in this EIS. The other actions that contribute to cumulative impacts can vary by resource and are defined independently for each resource. However, the underlying inputs, models, and assumptions of the CAFE model (Section 2.3.1, *CAFE Model*) already take into account many past, present, and reasonably foreseeable future actions that affect U.S. transportation sector fuel use and U.S. mobile source air pollutant emissions. For example, the CAFE model incorporates the 2017 Annual Energy Outlook (AEO), which includes assumptions and projections relating to fuel prices and vehicle miles traveled (VMT). The CAFE model also uses data generated by the Greenhouse Gases, Emissions, and Energy Use in Transportation (GREET) model, which incorporates U.S. air pollutant emissions regulations applicable to upstream processes. Further, the baseline of analysis for measuring the climate impacts of the Proposed Action and alternatives is based on a global emissions scenario that includes assumptions about known policies and initiatives that affect global GHG emissions. Therefore, analysis of direct and indirect impacts of the Proposed Action and alternatives inherently (and appropriately) incorporates projections about the impacts of past, present, and reasonably foreseeable future actions to develop a realistic baseline. Because the universe of other reasonably foreseeable actions that would combine with the Proposed Action and alternatives on the relevant resource areas is limited, this chapter supplements the earlier chapters in analyzing the incremental impacts of the Proposed Action and alternatives when added to other past, present, and reasonably foreseeable future actions.

For energy, air quality, and other impacts, the other actions considered in their respective cumulative impact analyses are predictable actions where meaningful conclusions on impacts or trends relative to impacts of the Proposed Action and alternatives can be discerned. For these impact areas, the impacts described in Chapters 3, 4, and 7 are related to the widespread use of gasoline and diesel fuel to power light-duty vehicles. Some evidence, however, suggests that manufacturers may introduce a higher proportion of electric vehicles (EV) into their fleets, which would affect the impacts reported in those chapters. This potential change in fuel source for light-duty vehicles is therefore a focus of the analysis in this chapter. In addition, NHTSA considers impacts related to new federal policies regarding energy production and use.

The cumulative impact analysis for GHG emissions and climate impacts is based on a global-scale emissions scenario because it is not possible to individually identify and define the incremental impact of each action during the analysis period (2020 through 2100) that could contribute to global GHG emissions and climate change. Instead, examples of some known actions that contribute to the underlying emission scenario provide a national and an international perspective.

8.3 Energy

8.3.1 Scope of Analysis

The timeframe for this analysis of cumulative energy impacts extends from 2020 through 2050, and the geographic area of interest is consumption of light-duty vehicle fuels within the United States. This temporal and geographic focus is consistent with the analysis of direct and indirect energy impacts in Chapter 3, *Energy*.

8.3.2 Analysis Methods

NHTSA's EIS for the MY 2017–2025 CAFE, which included analysis of the augural standards for MYs 2022–2025, evaluated cumulative impacts by estimating fuel economy improvements resulting directly or indirectly from the CAFE standards, plus additional improvements from actions taken by manufacturers, including potential over-compliance with CAFE standards through MY 2025 and ongoing fuel economy improvements after MY 2025. For this EIS, where such actions taken by manufacturers are anticipated to occur, they are incorporated in the CAFE model outputs and included in Chapter 3, *Energy*.

NHTSA has taken a fresh look at its analytical approach regarding the cumulative impacts of the Proposed Action and alternatives on energy. First, NHTSA considers recent federal policies that affect future energy production and use, thereby affecting fuel use. Second, while many combinations of individual technologies might be used to reduce fossil fuel use in light-duty vehicles, many vehicle manufacturers are looking beyond the internal combustion engine (ICE) to comply with CAFE standards. The CAFE model, which produces the estimates that underlie the analysis of impacts on energy, considers EV technologies among the various technologies manufacturers may incorporate to improve fuel economy. However, global EV market trends may provide additional insights about the future and could affect energy use beyond the impacts identified in Chapter 3, *Energy*. These trends provide insight on future actions that, in combination with the Proposed Action and alternatives, could further affect U.S. light-duty vehicle fuel consumption through 2050.

8.3.3 Other Past, Present, and Reasonably Foreseeable Future Actions

The following sections discuss reasonably foreseeable future actions related to transportation sector fuel use, including some federal policies that affect future energy production and use, and some global EV policies and market trends that may affect energy production and use.

A recent Presidential Executive Order on Promoting Energy Independence and Economic Growth (EO 13783, issued March 28, 2017) could substantively affect energy supply. EO 13783 requires that executive departments and agencies "review existing regulations that potentially burden the development or use of domestically produced energy resources and appropriately suspend, revise, or rescind those that unduly burden the development of domestic energy resources beyond the degree necessary to protect the public interest or otherwise comply with the law." The stated goal of this initiative is to "promote clean and safe development of our Nation's vast energy resources, while at the same time avoiding regulatory burdens that unnecessarily encumber energy production, constrain economic growth, and prevent job creation." EO 13783 also recognizes that "prudent development of these natural resources is essential to ensuring the Nation's geopolitical security."

Recent market trends indicate that global EV market share targets, quotas, and associated manufacturer investments to improve EV technologies and increase the scale of EV manufacturing may also affect U.S. transportation sector fuel use in the future. Global investments to comply with EV requirements outside the United States could reduce the cost of EVs and thereby increase U.S. EV demand beyond levels anticipated in the analysis of direct and indirect energy impacts.

However, the magnitude of this cumulative impact cannot be quantified with precision, and uncertainties surrounding the impacts of future government policies and subsidies and market-related factors make it difficult to predict how fleet mix shifts may actually affect transportation sector fuel use. Accordingly, this section presents a qualitative analysis of the impact on transportation fuel type and use attributable to potential EV adoption, with quantifiable estimates for U.S. cumulative fuel consumption impacts presented where available.

Section 8.3.3.1, *Global Electric Vehicle Market, Future Quotas, and Vehicle Industry Response*, explains how the global EV market trends may affect U.S. light-duty vehicle fuel consumption from 2020 through 2050. Section 8.3.3.2, *Recent Plug-In Electric Vehicles, Market Forecasts, and Potential Decline in Electric Vehicle Costs*, describes how these trends have increased forecasts for the EV share of global and U.S. light-duty vehicle sales through 2050, with associated declines in EV costs. Section 8.3.3.3, *Electric Vehicle Fuel Economy by Drive Cycle and Related Trends*, describes how an increase in U.S. EV sales could have an especially large impact on fuel use due to substantially higher EV fuel economy at slower speeds in congested traffic.

8.3.3.1 Global Electric Vehicle Market, Future Quotas, and Vehicle Industry Response

Currently available electric-drive vehicles are commonly categorized as follows:

- Battery electric vehicles (BEVs) are charged by plugging the vehicle into an electric power source such as the energy grid. BEVs have an electric motor, rather than an ICE, and produce zero tailpipe emissions.
- Hybrid electric vehicles (HEVs) are powered by an ICE in combination with an electric motor that uses energy stored in a battery. HEVs achieve higher fuel economy and lower tailpipe emissions by capturing energy normally lost during braking. This "regenerative braking" technology stores captured energy in the battery, but the battery cannot be recharged by plugging into the electric grid (AFDC 2018a).
- Plug-in hybrid electric vehicles (PHEVs) are HEVs that can also use electricity from an electric power source, such as the energy grid, that is stored in battery packs to run the vehicle. PHEVs generally have larger battery packs than other HEVs, which allow PHEVs to drive moderate distances using just electricity from the grid, producing zero tailpipe emissions during those intervals. When stored energy from the grid runs low, PHEVs run as HEVs, relying on an ICE in combination with an electric motor.
- Plug-in electric vehicles (PEVs) include BEVs and PHEVs, as both may be plugged into an electric power source.
- Fuel cell electric vehicles (FCVs) are powered by hydrogen and produce only water vapor and warm air as tailpipe emissions. FCVs and the hydrogen infrastructure to fuel them are still in an early stage of deployment (AFDC 2018b).

The global EV stock surpassed 2 million vehicles in 2016; however, this amounted to just 0.2 percent of all light-duty vehicles in use in 2016. PEV sales have been constrained by higher initial costs compared to ICE vehicles (primarily due to battery costs), the limited driving range on a fully charged battery, the limited infrastructure of public recharging stations, limited consumer options, uncertain resale value of EVs, and recent shifts in the market toward light trucks, among other factors.

PEV adoption has been significantly more prevalent than FCV adoption; of the 750,000 new light-duty PEV and FCV registrations in 2016, PEVs accounted for almost all the sales (IEA 2017). The 2016 PEV share of new light-duty vehicle sales was 29 percent in Norway, 6.4 percent in the Netherlands, 3.4 percent in Sweden, and about 1.5 percent in China, the United Kingdom, and France. China, the world's largest light-duty vehicle market, accounted for more than 40 percent of global 2016 PEV sales.

Preliminary data show that global PEV sales grew to 1.2 million in 2017, almost 60 percent higher than 2016 sales (Frost & Sullivan 2018). PHEVs accounted for about one-third of 2017 PEV sales, with BEVs accounting for two-thirds, continuing a trend of increasing BEV market share in the PEV segment. China had the largest 2017 increase in new PEV registrations, with PEV sales rising from 351,000 units in 2016 to more than 600,000 in 2017. In Europe, new PEV sales increased from 222,000 units in 2016 to more than 300,000 in 2017, as USA PEV sales increased from 157,000 units in 2016 to 200,000 in 2017.

Private and publicly accessible charging infrastructure for PEVs has grown at a rate similar to the annual growth rate of PEV sales (IEA 2017). PEVs outnumber public charging stations by more than six to one, indicating that most drivers rely primarily on private (home) charging. The expanding PEV charging infrastructure has also been associated with increases in the power output of PEV recharging equipment (reducing the time required for recharging) and the emergence of global interoperability objectives to use specific standards for sockets and connectors for normal and high-power recharging outlets.[4]

China has now established a program that effectively sets quotas for PEVs and FCVs, which are expected to make up at least 10 percent of each automaker's sales in China in 2019 an d 12 percent in 2020, with higher annual targets expected to be established for sales after 2020. China has not yet set a timetable to reach 100 percent EV sales, but is expected to join other nations in phasing out sales of ICE vehicles by 2040 (McDonald 2017).

The high PEV market share in Norway reflects substantial incentives to promote PEV sales, and the Norwegian Parliament has now set a goal that all new cars sold by 2025 should be zero- or low-emission vehicles (PEVs and FCVs) (Norsk elbilforening 2018). The Netherlands is also considering a ban on new ICEs by 2025 (Staufenberg 2016). In July 2017, France announced plans to end sales of new ICEs by 2040 (Chrisafis and Vaughan 2017). Just a few weeks later, Britain pledged that it would also ban new ICE cars and vans after 2040 (Asthana and Taylor 2017). Some federal states in Germany are also calling for a European Union phase-out of new ICE vehicles by 2030 (Sven Böll 2016), and India is considering a possible phase-out of new ICE vehicles by 2030 (The Times of India 2017). Other nations with PEV sales targets include Austria, Denmark, Ireland, Japan, Portugal, Korea, and Spain (Petroff 2017). Ten U.S. states (California, New York, New Jersey, Massachusetts, Oregon, Connecticut, Maine, Maryland, Rhode Island, and Vermont) have also adopted zero-emission vehicle targets that establish a 2 percent minimum (PEV and FCV) share of new vehicle sales in 2018, rising by 2 percent per year to 16 percent in 2025 (Loveday 2016).

The recently released 2018 AEO forecasts higher U.S. EV sales for 2030 through 2050. The change in EV forecasts from the 2017 AEO to the 2018 AEO reflects the global market trends that have developed rapidly over the past year, raising forecast sales for EVs. The 2017 and 2018 AEO forecasts are similar for FCV and HEV sales, with FCVs accounting for only about 0.5 percent of new light-duty vehicle sales through 2050, as HEVs rise to 3.7 percent of light-duty vehicle sales in 2020 and level off at less than 5 percent in 2030 through 2050.

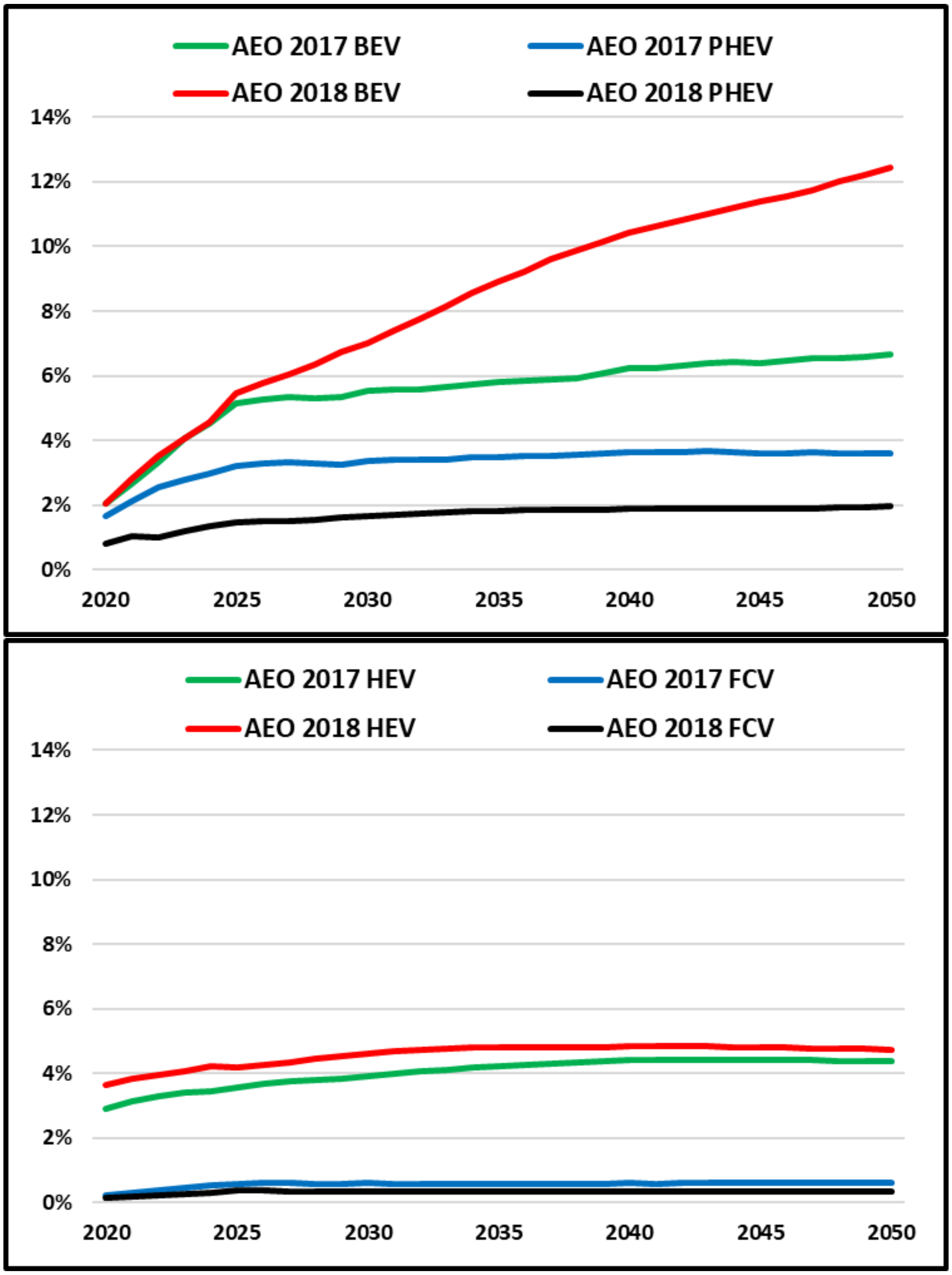
The larger change is in PEVs. The 2018 AEO forecast for 2030 through 2050 shows PHEV sales leveling off at just 2 percent of light-duty vehicle sales, versus almost 4 percent in the 2017 AEO. The new forecast also shows a steady increase in the BEV share of new light-duty vehicle sales from just more than 5 percent in 2025 to more than 12 percent in 2050, versus BEV growth in the 2017 AEO from about 5 percent in 2025 to 7 percent in 2050. The change in BEV forecasts is apparent only after 2025 and

[4] U.S. recharging infrastructure will also increase because of EPA partial settlements that require Volkswagen to invest $2 billion in ZEV charging infrastructure over the next decade.

appears to reflect the possibility of increasing market demand for BEVs as technology advances lower the cost of BEVs and extend the driving range on a fully charged battery.

Figure 8.3.3-1 shows the forecasted trend in the EV share of the market.

Figure 8.3.3-1. 2017 and 2018 Annual Energy Outlook Forecasts for Electric Vehicle Shares of New Light-Duty Vehicle Sales



AEO = Annual Energy Outlook; BEV = battery-operated vehicle; PHEV = plug-in hybrid vehicle; HEV = hybrid electric vehicle; FCV = fuel cell vehicle

Manufacturers have announced investments to meet higher EV targets in 2019 and beyond (Reuters 2017[5]):

- Volvo Cars has announced that all Volvo models launched after 2019 will be PEVs or hybrids.
- VW Group will have 80 new EV models by 2025, aiming for 2 million to 3 million EV sales across its brands, and expects all VW Group models will have electric versions by 2030.
- Toyota is aiming for all its vehicles to be zero emission by 2050 and is spending heavily on FCV technology and on solid-state batteries that Toyota hopes to commercialize by the first half of the 2020s.
- Renault-Nissan will launch 12 new EV models by 2022, and aims for 20 percent of its vehicles to be zero emission by 2020.
- BMW has announced plans for mass production of 12 new EV models by 2025.
- Daimler is investing 10 billion euros in electric and hybrid technology and aims for 100,000 annual EV sales by 2020. Daimler expects to have at least 50 electric or hybrid models by 2022, when Mercedes will offer an electric version of all its models.
- Ford plans for only a third of its vehicles to have ICEs by 2030. In December 2015, Ford announced it would invest $4.5 billion to introduce 13 "electrified" vehicles by 2022 (Priddle 2015) but these were mostly expected to be HEVs (Lienert and Carey 2017). In January 2018, Ford more than doubled this commitment, announcing plans to invest $11 billion to introduce 24 hybrids and 16 fully electric vehicles by 2022 (Marshall 2018).
- Tesla has launched its first mass-market EV, the Model 3, but struggled with production problems in 2017 and now expects to build 5,000 Model 3s per week by mid-2018, instead of its original target date of December 2017.
- General Motors expects to sell 1 million EVs a year by 2026, many of them in China. In October 2017, General Motors committed to launching 20 new EVs by 2023, including two new all-electric vehicles for the U.S. market in the next 18 months (CBS News 2017).

These public announcements may not fully or accurately reflect manufacturers' future product plans. In addition, if consumer demand for EVs does not meet expectations, manufacturers may reduce investments in their development, production, and availability. Changes in fuel prices, U.S. and global economic activity, consumer purchasing behavior, and government regulations could cause manufacturers to revise product and investment plans over time.

Specifically, other domestic policies, like EPA's proposed revocation of California's waiver for the Advanced Clean Car (ACC) program applicable to MYs 2022–2025, may affect the number of PEVs and FCVs that manufacturers produce. Because programs like California's ZEV mandate force investment in specific technology (electric and fuel cell technology) by incentivizing production through the use of credits, eliminating that incentive may allow manufacturers to employ other fuel saving and CO_2 emissions-reducing technologies to build fleets compliant with federal standards. Similarly, NHTSA's assertion of preemption under the Energy Policy and Conservation Act of 1975 (EPCA) and the Energy and Independence Security Act of 2007 (EISA) in regards to state laws or regulations relating to fuel economy standards, which touches the ZEV mandate and any state GHG standards that affect mobile source CO_2 emissions, may reduce the number of PEVs or FCVs that manufacturers build to produce fleets compliant with federal standards. While all manufacturers previously mentioned have a global

[5] Unless otherwise noted.

presence, it is unclear to what extent any domestic policies that affect the adoption of EVs will have on broader global EV adoption. Section VI of the Notice of Proposed Rulemaking (NPRM) provides a comprehensive discussion of these preemption proposals.

8.3.3.2 Recent Plug-In Electric Vehicle Market Forecasts and Potential Decline in Electric Vehicle Costs

In January 2018, Moody's forecast that BEVs will reach a 7 to 8 percent share of global light-duty vehicle sales by the mid-2020s, rising to 17 to 19 percent by 2030 "as battery costs drop, driving range improves and charging infrastructure expands" (Moody's 2018). Bloomberg forecasts that new PEV sales will be close to 10 percent of global light-duty vehicle sales by 2025 and projects that PEV sales will surpass ICE sales in 2038 (Shankleman 2017a) (Figure 8.3.3-2). Morgan Stanley forecasts BEV market share will rise to 16 percent of world light-duty vehicle sales in 2030, 51 percent by 2040, and 69 percent by 2050 (Lambert 2017) (Figure 8.3.3-3).

Figure 8.3.3-2. **Bloomberg Forecast for Global Plug-In Electric Vehicle and Internal Combustion Engine Light-Duty Vehicle Sales**

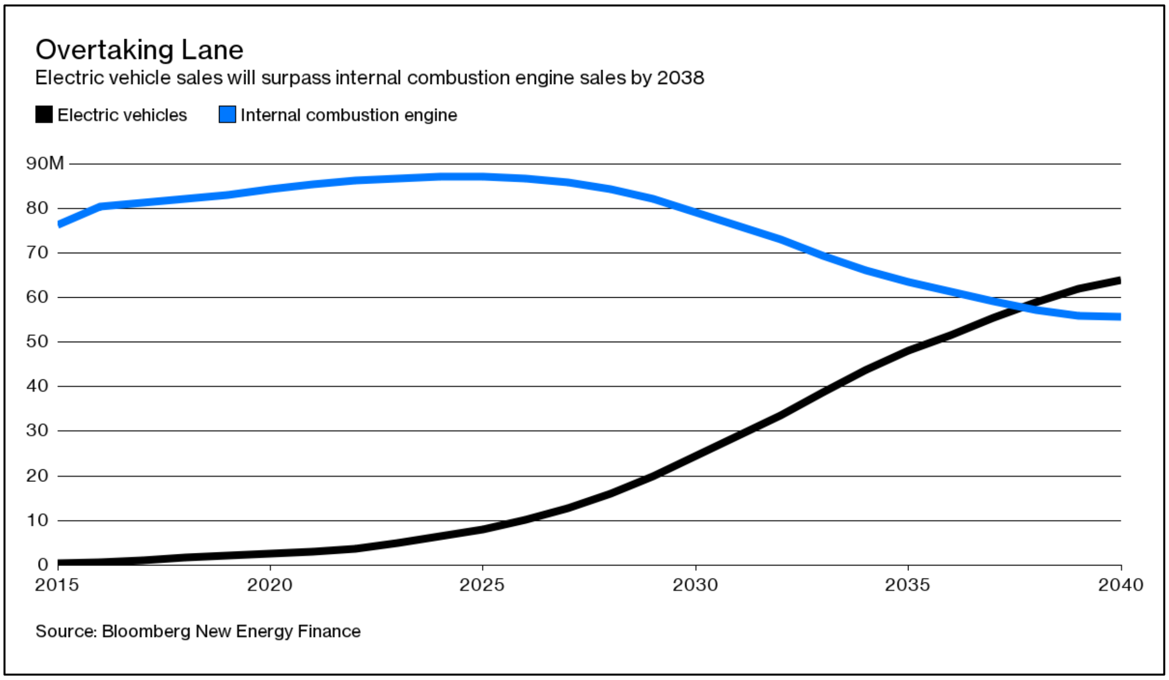
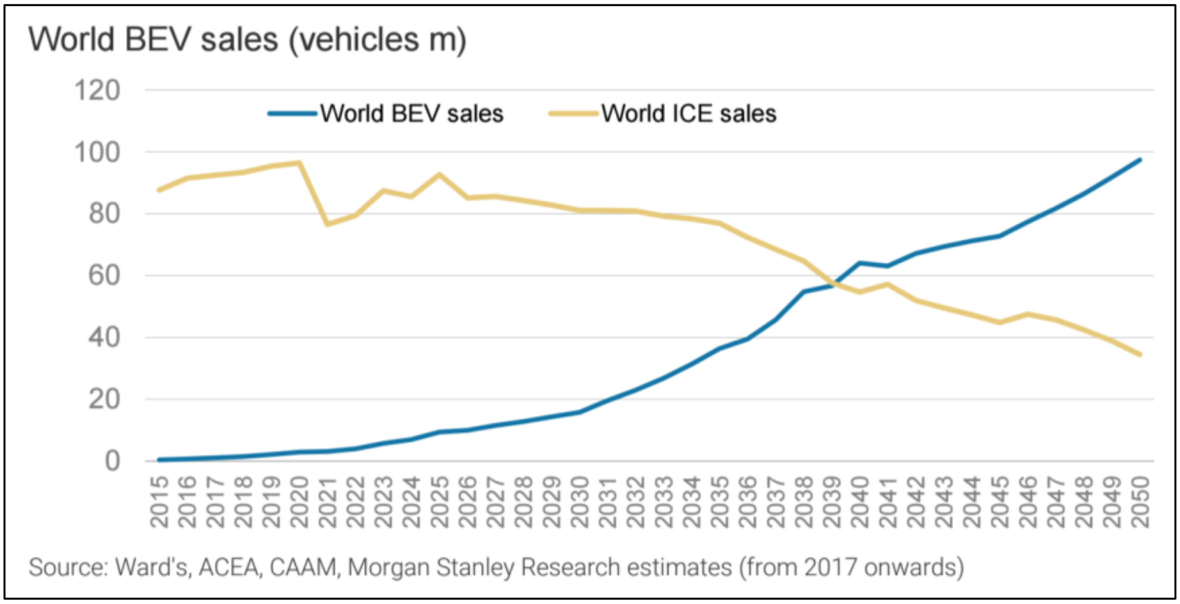


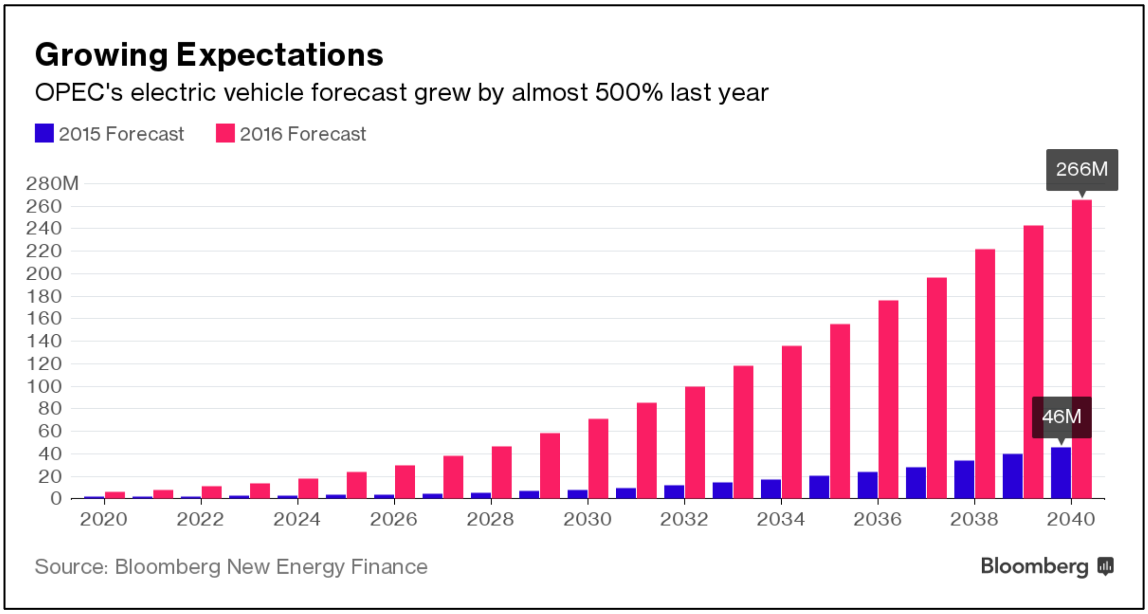
Figure 8.3.3-3. Morgan Stanley Forecast for Global Battery-Operated Vehicle and Internal Combustion Engine Light-Duty Vehicle Sales



BEV = battery operated vehicle; ICE = internal combustion engine

Bloomberg also expects that the total world stock of PEVs in use will rise to 530 million by 2040, accounting for a third of the global light-duty vehicle stock, and Bloomberg notes that many other forecasts have announced sharp upward revisions in the expected growth of the global PEV stock (Shankleman 2017b). The International Energy Agency raised its 2030 estimate of PEV stocks to 58 million from 23 million. Exxon Mobil boosted its 2040 estimate to about 100 million from 65 million. British Petroleum anticipates 100 million PEVs on the road by 2035, a 40 percent increase in its prior outlook. The largest revision is from OPEC, which raised its 2040 forecast to 266 million, up from 46 million in its prior year forecast (Figure 8.3.3-4). These sharp upward revisions reflect continuing uncertainty in long-term PEV sales and could be subject to future revisions upward or downward over time.

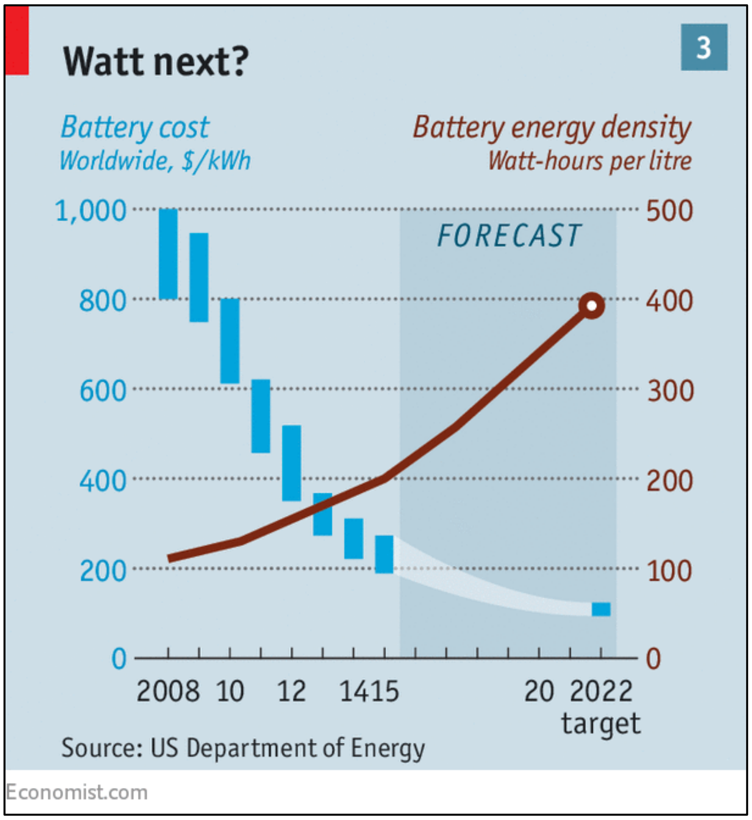
Figure 8.3.3-4. OPEC 2015 and 2016 Forecasts for Global Plug-In Electric Vehicle Stock



Moody's estimates that light-duty vehicle manufacturers are currently losing about $7,000 to $10,000 per PEV sold but expects PEVs to become profitable as the increasing scale of production lowers battery prices (Yoney 2018). Plans for at least 10 new lithium-ion battery gigafactories (capable of producing a billion batteries) were announced in the first half of 2016 (Deign 2017). Bloomberg reports that global battery-making capacity is set to reach 278 gigawatt-hours by 2021, compared to 103 gigawatt-hours in 2017 (Bloomberg New Energy Finance 2017). The potential for ongoing declines in battery costs is consistent with declines recorded over the past decade (Figure 8.3.3-5). *The Economist* reports that average lithium-ion cell costs have fallen from more than $1,000 per kilowatt-hour in 2010 to $130 to $200 per kilowatt-hour in 2016, as battery energy density has increased from 100 to 200 watt-hours per liter (San Diego and Sunderland 2017).

Bloomberg forecasts a continuing decline in battery costs to $109 per kilowatt-hour by 2025 and $73 per kilowatt-hour in 2030 (Figure 8.3.3-6). While some analysts question whether these forecasts are achievable, battery manufacturers have already surpassed a 2012 AEO forecast under a High-Technology Battery case scenario that projected battery costs of $150 per kilowatt-hour in 2030, and a 2012 AEO Reference case forecast of battery costs above $500 per kilowatt-hour through 2020 and well above $250 per kilowatt-hour in 2035 (EIA 2012b) (Figure 8.3.3-7).

Figure 8.3.3-5. Past and Forecast Trends in Battery Cost and Energy Density



kWh = kilowatt hour

Figure 8.3.3-6. Bloomberg Forecast for Battery Costs through 2030

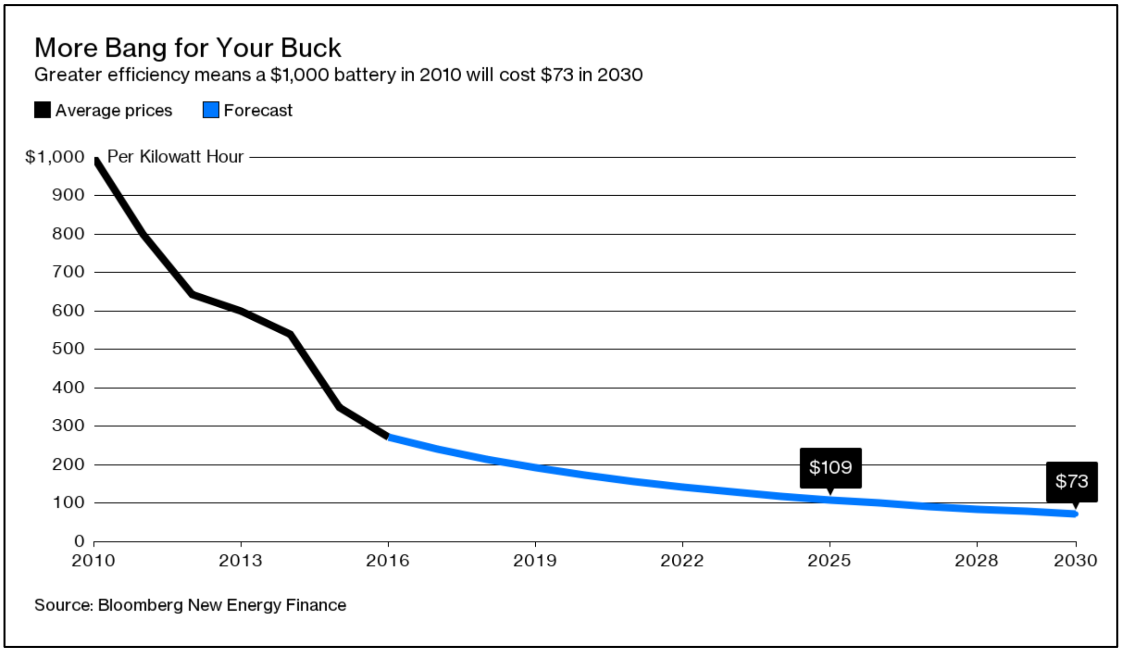
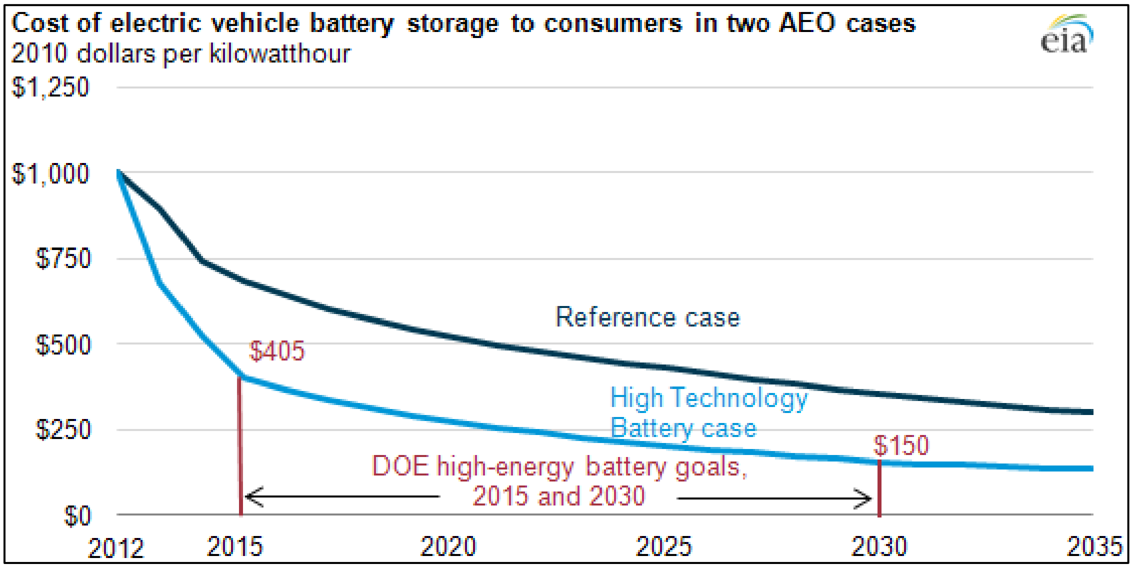


Figure 8.3.3-7. Annual Energy Outlook 2012 Battery Cost Forecasts for Reference Case and High Technology Battery Case



AEO = Annual Energy Outlook; DOE = Department of Energy

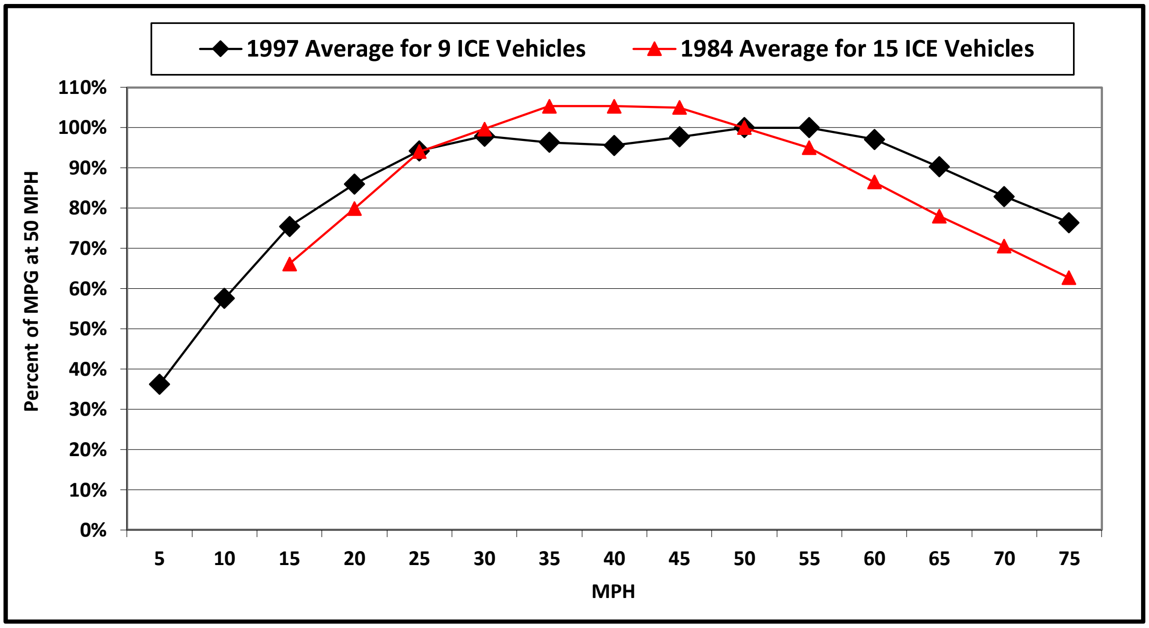
8.3.3.3 Electric Vehicle Fuel Economy by Drive Cycle and Related Market Trends

Global industry investments in PEVs and declines in PEV battery costs indicate that the cost of PEVs to consumers may decline over time. These global market forces could increase market demand for PEVs. An increase in the PEV share of light-duty vehicle sales would increase overall light-duty vehicle fuel economy due to the higher miles-per-gallon equivalent (MPGe) for PEVs. Additionally, EVs are likely to be used more intensively in congested traffic where regenerative braking further increases EV fuel economy compared to ICEs.

For comparable cars, HEVs achieve better highway mpg than ICEs, and BEVs achieve much higher highway MPGe; however, the gap in city mpg is much higher when comparing an EV to and ICE vehicle. HEVs and BEVs achieve much better city mpg because regenerative braking recharges batteries during the frequent stops associated with city driving. The EPA city drive cycle test (a component of EPA fuel economy ratings) has 23 stops, resulting in EV city mpg that is higher than highway mpg. For ICE vehicles, EPA highway mpg is always higher than city mpg because the highway drive cycle test has no stops.

Comparing ICE city mpg with BEV city MPGe also understates the BEV advantage for drivers who frequently travel in slower stop-and-go traffic. Studies of mpg by steady miles per hour (mph) show that ICE mpg is similar at speeds of 30 to 60 mph, but mpg falls by 10 to 25 percent at speeds of 15 to 20 mph, and by 40 to 60 percent at 5 to 10 mph (Figure 8.3.3-9). The EPA highway test is almost entirely in the peak mpg speed range of 30 to 60 mph, and more than 99 percent of highway test miles are at speeds above 20 mph. The EPA city mpg is based on a drive cycle with a significant percentage of miles at speeds below 30 mph but with less than 20 percent of test miles at speeds below 20 mph. Therefore, even the EPA city mpg ratings may overstate mpg for ICE vehicles used by drivers with daily commutes in congested stop-and-go traffic at speeds below 20 mph.

Figure 8.3.3-8. Internal Combustion Engine Vehicle Miles per Gallon by Steady Speed Miles per Hour

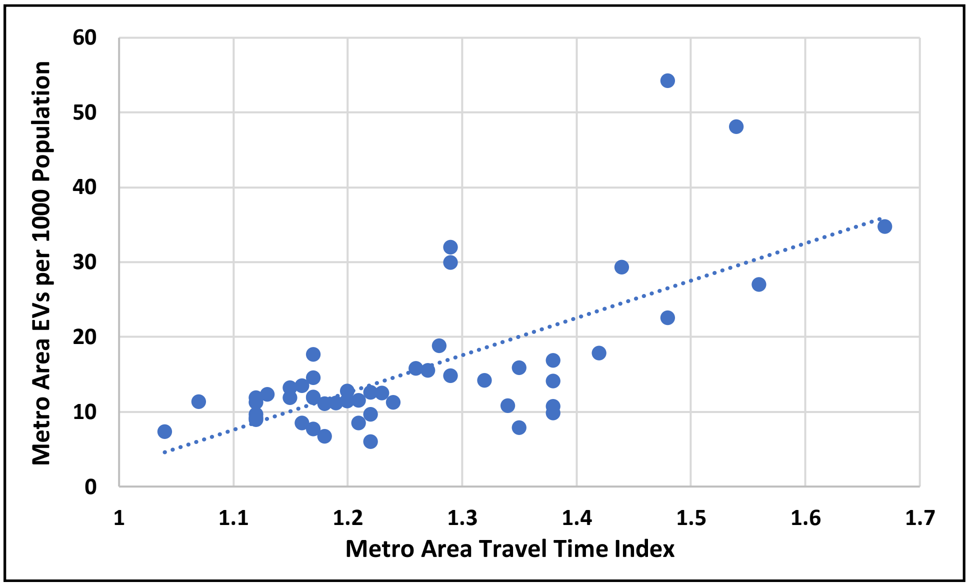


ICE = internal combustion engine; MPH = miles per hour; MPG = miles per gallon

EVs with regenerative braking (HEVs, PHEVs, and BEVs) are also more concentrated in areas with the worst traffic congestion, as measured by travel time index (TTI) (FHWA 2017). TTI is a ratio of peak-period travel time to free-flow travel time during the AM (6 am to 9 am) and PM (4 pm to 7 pm) peak traffic times on weekdays (weighted by VMT). A TTI of 1.5 means that a commute distance that would take 40 minutes in free-flow traffic would stretch to 60 minutes during peak commuter traffic times, with an associated reduction in average speed. Figure 8.3.3-10 shows a scatter plot of EV registrations per 1,000 population and TTI for 51 U.S. metro areas, and the trend line shows that metro areas with the worst commuter traffic congestion (highest TTIs) have a much higher concentration of EV registrations per 1,000 population. The possible implication is that consumers recognize the greater fuel economy of EVs in congested traffic, resulting in EVs being especially concentrated in metro areas with the most congested traffic.[6]

[6] Other possible contributors to this effect, which may be correlated with large metro areas, include range anxiety, EV incentives, affluence, and environmental concerns.

Figure 8.3.3-9. Travel Time Index and Electric Vehicle Registrations per 1,000 population by Metro Area



EV= electric vehicle

8.3.4 Cumulative Impacts on Energy

With regard to federal energy policy, the ongoing implementation of EO 13783 could affect cumulative energy impacts in many different ways. Eliminating unnecessary regulatory burdens that restrain oil exploration could increase U.S. oil production and thereby reduce the price of gasoline and diesel fuel. Consequently, these lower fuel prices could increase U.S. vehicle operation (similar to the rebound effect) and thereby increase use of these fuels. It is also possible that eliminating regulatory burdens that increase the cost of electricity could reduce the electricity cost of operating EVs and thereby increase demand for EVs. The cumulative impacts of deregulation could also vary over time. For example, many vehicle manufacturers have stated that they expect substantial growth in the EV share of light-duty vehicles over the next 10 to 20 years (Section 8.3.3.3, *Electric Vehicle Fuel Economy by Drive Cycle and Related Market Trends*), but many of those same manufacturers are relying on robust sales of ICE vehicles, including light trucks, to generate the profits they expect to invest in new EV technologies and manufacturing over the next decade. This perspective suggests that eliminating unnecessary regulatory burdens could increase gasoline and diesel fuel use over the next decade, while supporting economic growth and light-duty ICE vehicle sales at levels that could allow manufacturers to fund longer-term growth in the EV share of future light-duty vehicle sales.

With regard to EV market trends, the 2018 AEO forecast showing a steady increase in the BEV share of new light-duty vehicle sales to more than 12 percent in 2050, versus the 2017 AEO forecast of a 7 percent BEV share in 2050, is associated with a decrease of approximately 3 percent in total 2020 through 2050 light-duty vehicle fuel use in the 2018 AEO versus the 2017 AEO. This rough estimate of the fuel use change is attributed to a gradual increase in the forecast BEV share of the vehicle stock from 2020 through 2050 (with a larger decline in gasoline use partially offset by an increase in light-duty vehicle electricity use) and does not reflect other changes in the light-duty vehicle fuel forecast from the 2017 AEO to the 2018 AEO. This AEO revision is consistent with PEV forecasts from other sources discussed previously, which suggest that growth in the PEV share of new U.S. light-duty vehicle sales could be faster than previously anticipated, but there is considerable uncertainty associated with all the forecasts through 2050.

8.4 Air Quality

8.4.1 Scope of Analysis

The timeframe for the cumulative air quality impact analysis extends from 2020 through 2050. This analysis focuses on potential U.S. air quality impacts associated with changes in the U.S. light-duty vehicle fleet that could result from new federal energy policy and global market trends, but the geographic area of interest is U.S. emissions sources (upstream and downstream). This temporal and geographic focus is consistent with the analysis of direct and indirect air quality impacts in Chapter 4, *Air Quality*.

8.4.2 Analysis Methods

The methods NHTSA used to characterize the impacts of the Proposed Action and alternatives on emissions and air quality are described in Section 4.1.2, *Methods*. The methods and assumptions for the cumulative analysis are qualitative rather than quantitative because of uncertainties in future trends, particularly in the generation mix of the power sector, future energy prices, the rate of adoption of EVs as battery costs continue to decrease, and consumer behavior in EV usage and charging. Changes in the generation mix could affect the emissions associated with fuel feedstock extraction and refining, fuel storage, and fuel distribution, as well as upstream emissions associated with charging EVs.[7]

8.4.3 Other Past, Present, and Reasonably Foreseeable Future Actions

As discussed in Chapter 4, *Air Quality,* aggregate emissions associated with vehicles have decreased substantially since 1970, even as VMT has nearly doubled. The primary actions that have resulted in downstream emissions decreases from vehicles are the EPA Tier 1, Tier 2, and Tier 3 Motor Vehicle Emission and Fuel Standards. EPA has issued similar emission standards for transportation sources other than motor vehicles, such as locomotives, marine vessels, and recreational vehicles, as well as standards for engines used in construction equipment, emergency generators, and other nonvehicle sources.

Upstream emissions associated with vehicles also have decreased (on a per-gallon fuel basis) since 1970 as a result of continuing EPA and state regulation of stationary emissions sources associated with fuel feedstock extraction and refining, and with power generation (on a per-kilowatt hour basis). EPA regulations relevant to stationary source emissions include New Source Performance Standards, National Emissions Standards for Hazardous Air Pollutants, the Acid Rain Program under Title IV of the Clean Air Act, the Cross-States Air Pollution Rule, and the Mercury and Air Toxics Standards Rule. State air quality agencies have issued additional emission control requirements applicable to stationary sources as part of their State Implementation Plans.

As discussed in Section 8.3, *Energy*, market-driven changes in the energy sector—in particular, the rate of U.S. adoption of EVs as battery costs continue to decrease—are expected to affect U.S. emissions and could result in future increases or decreases in emissions. Potential changes in federal regulation of

[7] Increased adoption of EVs would eliminate the tailpipe emissions of conventional vehicles that are displaced but would increase the upstream emissions from power plants generating the electricity that charges the EVs.

energy production and emissions from industrial processes and power generation also could result in future increases or decreases in aggregate emissions from these sources.

8.4.4 Cumulative Impacts on Air Quality

EO 13783 could substantively affect energy supply and use by increasing the production of domestic fossil energy resources and eliminating regulations that inhibit the use of those resources. Additional petroleum extraction and refining could increase supply and lower consumer gas prices, resulting in increased market demand for less fuel-efficient passenger cars and light trucks, increased VMT, or both. This could result in additional emissions of certain criteria and toxic air pollutants. Additional coal, oil, and natural gas production could create more abundant supply, driving down their cost and increasing their use in the power generation sector. As described in Chapter 3, *Energy*, in recent years, the electric utilities have been shifting away from coal toward natural gas and renewable energy due in part to the regulatory costs associated with coal plants and the cheap, abundant supply of natural gas. By reducing regulatory burdens associated with fossil energy production and use, the electrical grid could shift increasingly toward coal and natural gas, increasing emissions of criteria pollutants compared to renewable energy sources. To the degree to which fuel use in the light-duty transportation sector increases, upstream energy use associated with feedstock extraction and refining, distribution, and storage would increase proportionally, thereby increasing emissions associated with that upstream energy use.

Additionally, as discussed in Section 8.3, *Energy*, as manufacturers respond to the potential demands of the global market for EVs, the number and variety of EVs and their capabilities and driving ranges available to U.S. customers may increase. To the extent that U.S. EV sales increase at greater rates than forecasted for the direct and indirect impacts analysis in Chapter 4, *Air Quality*, tailpipe emissions would decrease and upstream emissions from electricity generation would increase.

Temporal patterns in charging of EVs by vehicle owners would affect any increase in power plant emissions. Electrical grid operators optimize costs and reliability by dispatching power plants in different combinations depending on the varying demand for electricity. As a result, overall emission rates from the power plant fleet (the set of power plants as a whole) are different during hours of peak electrical demand, when peak-load power plants are operating, compared to emission rates during off-peak hours, when predominantly base-load power plants are operating. See Section 6.2.3.2, *Marginal Grid Greenhouse Gas Intensity*, for additional detail on emission variations from the timing of electricity consumption and EV charging.

Trends in the prices of fossil fuels and the costs of renewable energy sources will affect the generation mix and, consequently, the upstream emissions from EVs. Continuation of the current relatively low prices for natural gas would encourage continued substitution of natural gas for other fossil fuels. Continued decreases in the costs of renewable energy would encourage substitution of renewable energy sources for fossil fuels. Continuation of either of these economic trends likely would lead to lower total emissions from EV charging. Conversely, a reversal of these trends because of new federal energy policies would lead to higher total emissions from EV charging.

The forecasts of power generation emissions used in the CAFE model account for existing legislation and other regulatory actions that affect power plant emissions, such as the Cross-States Air Pollution Rule and the Mercury and Air Toxics Rule. To the extent that these requirements may be amended in future years when the EV percentage of light-duty vehicle sales has increased, power sector emissions for EV charging would change accordingly.

Similarly, the forecasts of upstream and downstream emissions that underlie the impact analysis assume the continuation of current emissions standards (including previously promulgated future changes in standards) for vehicles, oil and gas development operations, and industrial processes such as fuel refining. These standards have become more stringent over time as state and federal agencies have sought to reduce emissions to help bring nonattainment areas into attainment. To the extent that the trend toward more stringent emissions standards could change in the future, total nationwide emissions from vehicles and industrial processes could change accordingly.

Cumulative changes in health impacts due to air pollution are expected to be consistent with trends in emissions. Higher emissions would be expected to lead to an increase in overall health impacts while lower emissions would be expected to lead to a decrease in health impacts, compared to conditions in the absence of cumulative impacts.

8.5 Other Impacts

8.5.1 Scope of Analysis

Resource areas covered in the cumulative analysis are the same as those addressed in the direct and indirect impact analysis (Chapter 7, *Other Impacts*), including land use and development, hazardous materials and regulated wastes, historical and cultural resources, noise, and environmental justice. The timeframe for this analysis of other cumulative impacts extends from 2020 through 2050. This analysis considers potential impacts associated with global light-duty vehicle market trends, but the geographic area of interest is the United States. This temporal and geographic focus is consistent with the analysis of other direct and indirect impacts in Chapter 7.

8.5.2 Analysis Methods

The analysis methods for assessing cumulative impacts on the resource areas described in this section are consistent with the methods for determining direct and indirect impacts (Chapter 7, *Other Impacts*). However, the cumulative impact scenario considers the additional actions described in Section 8.5.3, *Other Past, Present, and Reasonable Foreseeable Future Actions*.

8.5.3 Other Past, Present, and Reasonably Foreseeable Future Actions

The analysis of other cumulative impacts builds upon the cumulative analysis for energy and air quality as described in Section 8.3.3, *Other Past, Present, and Reasonable Foreseeable Future Actions* (energy) and 8.4.3, *Other Past, Present, and Reasonable Foreseeable Future Actions* (air quality).

8.5.4 Cumulative Impacts on Other Resources

8.5.4.1 Land Use and Development

In terms of impacts on land use and development, an increase in petroleum supply or EV usage could result in an increase in VMT due to reduced fuel cost per mile (the rebound effect). In areas where the highway network, infrastructure availability, and housing market conditions allow, this could increase demand for low-density residential development beyond existing developed areas. Undeveloped land could be converted to support low-density suburban sprawl (FHWA 2014, DOT 2016c). Many agencies, however, are implementing measures, such as funding smart-growth policies, to influence settlement patterns in order to reduce VMT and fuel use to meet climate change goals (Moore et al. 2010, EPA

2017a). See Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, for more information regarding VMT.

Additionally, increases in fuel use resulting from reduced fuel costs or lower fleet-wide fuel economy could result in the need for additional oil extraction and refining, along with a potential need for new pipelines. Cumulative increases in EV use, however, may offset these increases in oil use, reducing the need for new capacity. In terms of biofuels, although the Proposed Action and alternatives are not anticipated to directly affect biofuel production and use in any predictable way, cumulative biofuel usage may increase as a result of new federal policies that promote the development of domestic fuel resources. Consequently, additional land use may be devoted to agricultural use and feedstock extraction for the production of biofuels.

8.5.4.2 Hazardous Materials and Regulated Wastes

In terms of impacts on hazardous materials and regulated wastes, an increase in EV usage could decrease fuel production and combustion, offsetting the potential increases that may result from the Proposed Action and alternatives (Chapter 3, *Energy*). This would lead to an overall decrease in wastes generated from fuel extraction, production, and combustion, and a decrease in the number of hazardous material spills from extraction and refining. On the other hand, reduced fuel costs could result in consumer demand for less fuel-efficient vehicles or increased VMT, resulting in the opposite impacts. In addition, increased EV usage may result in an increase in wastes associated with the production and disposal of EV batteries. See Chapter 6, *Life-Cycle Assessment of Vehicle Energy, Material, and Technology Impacts*, and Chapter 7, *Other Impacts*, for additional discussions of the waste impacts associated with EV usage.

8.5.4.3 Historical and Cultural Resources

As noted in Chapter 7, *Other Impacts* the main impact on historical and cultural resources associated with the Proposed Action and alternatives is the potential for increased acid rain and deposition. Acid rain and deposition corrodes metals and other building materials, reducing their historic and cultural value. Increases in EV usage have the potential to reduce fuel production and consumption impacts, thereby reducing pollutant emissions that cause acid rain and deposition and decreasing impacts on historical and cultural resources. Conversely, such emissions and impacts would increase if reduced fuel costs result in increased consumer demand for less fuel-efficient vehicles or increased VMT.

8.5.4.4 Noise and Safety Impacts on Human Health

An increase in EV usage could reduce noise levels on roads and highways throughout the United States. However, as discussed in Chapter 7, *Other Impacts*, noise reductions from increased use of hybrid technologies could be offset at low speeds by manufacturer installation of pedestrian safety-alert sounds, as required by NHTSA (NHTSA 2016b). Conversely, decreased EV usage or increased driving associated with reduced fuel costs could result higher noise levels on roads and highways throughout the United States.

8.5.4.5 Environmental Justice

Potential decreases in fuel production and consumption associated with increased EV usage may offset some of the potential increases in fuel production and consumption associated with the Proposed Action and alternatives. This would offset any increases in direct land disturbance resulting from oil exploration and extraction as well as any increases in air pollution produced by oil refineries. To the extent that minority and low-income populations live closer to oil extraction, distribution, and refining facilities or are more susceptible to their impacts (e.g., emissions, vibration, or noise) they are less likely to experience cumulative impacts resulting from these activities. Conversely, to the extent that EO 13783 results in increased oil extraction and refining, as well as increased vehicle operation due to reduced fuel prices, minority and low-income populations may experience increased impacts, but again, only to the extent that such populations are present near emissions sources. As noted in Chapter 7, *Other Impacts*, a correlation between proximity to oil refineries and the prevalence of low-income and minority populations has not been established in the scientific literature. Therefore, disproportionate impacts on minority and low-income populations due to their proximity to oil refineries are not foreseeable. In addition, the magnitude of the change in emissions relative to the baseline would not be characterized as high and adverse.

Increased EV usage also has the potential to reduce criteria and toxic air pollutant impacts, while increased fuel supply and reduced fuel prices could have the opposite effect. Overall cumulative impacts on minority and low-income populations related to criteria and hazardous air pollutant emissions, including human health impacts, would likely be proportional to increases or decreases in such emissions and would not be characterized as high and adverse.

Lastly, there is evidence that minority and low income populations may be disproportionately susceptible to the cumulative impacts of climate change. Because minority and low-income populations might have less of an ability to adapt to these impacts, these populations could be disproportionately affected compared to the overall population. Although the action alternatives would increase CO_2 concentration and temperature under the cumulative impact analysis, the increase would be a small fraction of the total increase in CO_2 concentrations and global mean surface temperature and would not be characterized as high and adverse. See Section 8.6.4, *Cumulative Impacts on Greenhouse Gas Emissions and Climate Change*, for a discussion of the cumulative impacts of the Proposed Action and alternatives. See Section 8.6.5, *Health, Societal, and Environmental Impacts of Climate Change*, for a thorough discussion of the cumulative impacts of climate change on minority, low-income, and other vulnerable populations.

8.6 Greenhouse Gas Emissions and Climate Change

Climate modeling conducted for this cumulative impacts analysis applies different assumptions about the effect of broader global GHG policies on emissions outside the U.S. passenger car and light truck fleets. The analysis of cumulative impacts also extends to include not only the immediate effects of GHG emissions on the climate system (atmospheric carbon dioxide [CO_2] concentrations, temperature, sea level, precipitation, and ocean pH) but also the impacts of past, present, and reasonably foreseeable future human activities that are changing the climate system on key resources (e.g., freshwater resources, terrestrial ecosystems, and coastal ecosystems).

8.6.1 Scope of Analysis

The timeframe for the cumulative GHG and climate change impact analysis extends from 2020 through 2100. This analysis considers potential cumulative GHG and climate change impacts associated with broader global GHG emissions policies in combination with the Proposed Action and alternatives. The geographic area of interest is domestic and global, as cumulative impacts of changes in GHG emissions occur on a domestic and global scale. This temporal and geographic focus is consistent with the analysis of direct and indirect GHG and climate change impacts in Chapter 5, *Greenhouse Gas Emissions and Climate Change*. A medium-high global emissions scenario that takes into account a moderate reduction in global GHG emissions was used in the climate modeling. This is consistent with global actions to reduce GHG emissions; specific actions that support the use of this scenario were included as examples.

8.6.2 Analysis Methods

The methods NHTSA used to characterize the impacts of the Proposed Action and alternatives on climate are described in Section 5.3, *Analysis Methods*. The methods and assumptions for the cumulative analysis are largely the same as those used in the direct and indirect impacts analysis, except for the global emissions scenario in the main analysis and the global emissions scenarios in the sensitivity analysis.

8.6.2.1 Global Emissions Scenarios Used for the Cumulative Impact Analysis

For the GHG and climate change analysis, cumulative impacts were determined primarily by using the Global Climate Change Assessment Model (GCAM) 6.0 scenario as a reference case global emissions scenario that assumes a moderate level of global actions to address climate change. NHTSA chose the GCAM 6.0 scenario as a plausible global emissions baseline because of the potential impacts of these reasonably foreseeable actions, yielding a moderate level of global GHG reductions from the GCAM Reference baseline scenario used in the direct and indirect analysis. For the cumulative analysis, the GCAM 6.0 scenario serves as a reference scenario against which the climate impacts of the Proposed Action and alternatives can be measured.

To evaluate the sensitivity of the results to a reasonable range of alternative emissions scenarios, NHTSA also used the RCP4.5 scenario and the GCAM Reference emissions scenario. The RCP4.5 scenario is a more aggressive stabilization scenario that illustrates the climate system response to stabilizing the anthropogenic components of radiative forcing at 4.5 watts per square meter in 2100.[8]

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 parts per million (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 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. Consequently, NHSTA believes that GCAM 6.0 represents a reasonable proxy for the past, present, and

[8] Radiative forcing is the net change in Earth's energy balance and is used in climate modeling to quantify the climate's response to change due to a perturbation. Small changes in radiative forcing can have large implications on surface temperature and sea ice cover. The radiative forcing from scenarios of future emissions projections are benchmarks used to understand the drivers of potential future climate changes and climate response scenarios (IPCC 2013b).

reasonably foreseeable GHG emissions through 2100, and is used for that purpose in this cumulative impact analysis on GHG emissions and climate change.

For the cumulative impact analysis, the difference in annual GHG emissions under the Proposed Action and alternatives and under the No Action Alternative was calculated. This change was then applied to the GCAM 6.0 scenario to generate modified global-scale emissions scenarios, which show the impact of the Proposed Action and alternatives on the global emissions path. For example, using the GCAM 6.0 scenario, emissions from passenger cars and light trucks in the United States in 2020 under the No Action Alternative are estimated to be 1,101 million metric tons of carbon dioxide ($MMTCO_2$); emissions in 2020 under Alternative 1 are estimated to be 1,108 $MMTCO_2$. The difference of 7 $MMTCO_2$ represents the increase in cumulative emissions projected to result from Alternative 1. Cumulative 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 passenger cars and light trucks in the United States under the No Action Alternative. Cumulative global emissions under Alternative 1 are, therefore, estimated to be 7 $MMTCO_2$ more than this reference level or 37,529 $MMTCO_2$ in 2020 under the cumulative impacts analysis.

8.6.2.2 Sensitivity Analysis

The methods and assumptions for the sensitivity analysis are largely the same as those used in the direct and indirect impacts analysis, with the exception of the climate scenarios chosen. 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).

8.6.3 Other Past, Present, and Reasonably Foreseeable Future Actions

NHTSA chose the GCAM 6.0 scenario as the primary global emissions scenario for evaluating climate impacts because regional, national, and international initiatives and programs now in the planning stages or already underway indicate that a moderate reduction in the growth rate of global GHG emissions is reasonably foreseeable in the future.

The following initiatives and programs are evidence of the past, present, or reasonably foreseeable actions to reduce GHG emissions. These domestic and global actions indicate that a moderate reduction in the growth rate of global GHG emissions is reasonably foreseeable in the future. NHTSA used this scenario to assess the impacts of the Proposed Action and alternatives when reasonably foreseeable increases 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 global efforts toward achieving GHG reductions. 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.

8.6.3.1 United States: Regional Actions

The following actions in the United States are already underway or reasonably foreseeable:

- **Regional Greenhouse Gas Initiative (RGGI).** Launched in January 1, 2009, the RGGI was the first mandatory, market-based effort in the United States to reduce GHG emissions (RGGI 2009). Nine Northeast and Mid-Atlantic States (Connecticut, Delaware, Maine, Maryland, Massachusetts, New

Hampshire, New York, Rhode Island, and Vermont)[9] 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, 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 70 to 80 $MMTCO_2$ below 2005 levels (C2ES 2013). In August 2017, RGGI states announced an overall cap reduction of 30 percent between 2020 and 2030 (C2ES 2017). The proposed changes include a cap of 68 $MMTCO_2$ in 2021, which will decline by just more than 2 $MMTCO_2$ per year until 2030 (RGGI 2017).

- **California 2016 Greenhouse Gas Reduction Legislation (Senate Bill 32)**. In 2016, California passed Senate Bill 32, which codifies into law a GHG emissions reduction target of 40 percent below 1990 levels by 2030, equivalent to an absolute level of 260 $MMTCO_2e$ (CARB 2017). Initiatives to support this goal seek to reduce GHGs from cars, trucks, electricity production, fuels, and other sources. GHG-reduction measures under the California Air Resources Board's 2017 proposed scoping plan update include a continuation of the state's cap and trade program, a renewable portfolio standard, reduction of electric sector GHG emissions through the integrated resources plan process, low carbon fuel standards, zero emission and plug-in hybrid light-duty electric vehicle deployment, medium and heavy-duty vehicle GHG regulations, VMT reduction programs, the Short-Lived Climate Plan to reduce non-CO_2 GHGs, and refinery sector GHG regulations (CARB 2017).[10] Each of these measures is a known commitment, or already underway or required, except for refinery sector GHG regulations and extending the state's cap-and-trade program beyond 2020. 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 2014). The known commitments are projected to reduce GHG emissions to 310 $MMTCO_2e$ by 2030, relative to a business-as-usual scenario of 392 $MMTCO_2e$ (CARB 2017).

8.6.3.2 United States: Federal Actions

The following federal actions are already underway or reasonably foreseeable:

- **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 further improve the fuel economy of and reduce GHG emissions for passenger cars and light trucks, as described in Chapter 1, *Purpose and Need for the Proposed Action*. The standards were projected to reduce average CO_2 emissions from new U.S. light-duty vehicles by 3.5 percent per year for MYs 2017–2021 (NHTSA and EPA 2011).
- **NHTSA and EPA Joint Phase 1 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 commercial medium- and heavy-duty on-highway vehicles and work trucks. The agencies' standards apply to highway vehicles and engines that are not regulated by the light-duty vehicle CAFE and GHG standards. NHTSA's Phase 1 mandatory standards for heavy-duty vehicles and engines began for MY 2016 vehicles, with voluntary standards for MYs 2014–2015. EPA's mandatory standards for heavy-duty vehicles began for MY 2014 vehicles. The agencies estimated that the combined standards would reduce CO_2

[9] New Jersey was a part of RGGI at its founding, but dropped out of the program in May 2011. On January 29, 2018, New Jersey Governor Phil Murphy signed an executive order directing the state to rejoin RGGI.

[10] NHTSA notes that its proposal asserts and seeks comment on the extent that EPCA expressly preempts state and local laws relating to fuel economy standards, as well as the implied preemption of state and local laws that act as obstacles to achieving the goals of EPCA.

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).

- **NHTSA and EPA Joint Phase 2 Rule on GHG Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Vehicles, MYs 2018 and Beyond.** In August 2016, NHTSA and EPA published the Phase 2 joint final rules to increase fuel efficiency and GHG standards for heavy-duty vehicles. As with the Phase 1 standards, the Phase 2 standards apply to highway vehicles and engines that are not regulated by the light-duty vehicle CAFE and GHG standards. NHTSA and EPA Phase 2 standards apply to MYs 2018–2027 for certain trailers and to MYs 2021–2027 for heavy-duty vehicle engines, Classes 7–8 tractors (combination heavy-haul tractors), Classes 2–8 vocational vehicles (buses and work trucks), and Classes 2b–3 heavy-duty pickups and vans (large pickup trucks and vans). The agencies estimated that the combined standards would reduce CO_2 emissions by approximately 1.1 billion metric tons and save up to 2 billion barrels of oil over the lifetime of vehicles sold during MYs 2018–2027 (NHTSA 2016c).
- **Renewable Fuel Standard 2 (RFS2).** Section 211(o) of the Clean Air Act requires that a renewable fuel standard be determined annually that is applicable to refiners, importers, and certain blenders of gasoline and diesel fuel. Based on this standard, each obligated party determines the volume of renewable fuel that it must ensure is consumed as motor vehicle fuel. RFS2, which went into effect July 1, 2010, increases the volume of renewable fuel required to be consumed in the transportation sector from the baseline of 9 billion gallons in 2008 to 36 billion gallons by 2022, as written in 2010. Since 2014, the volumetric requirements have been modified to account for lower than expected growth in advanced and cellulosic biofuels (EPA 2015d).[11] The 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.
- **United States Appliance and Equipment Standards Program.** The National Appliance Energy Conservation Act of 1987 established minimum efficiency standards for many household appliances and has been authorized by Congress through several statutes. Since its inception, the program has implemented additional 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).

8.6.3.3 International Actions

The following international actions are already underway or reasonably foreseeable:

- **United Nations Framework Convention on Climate Change and the annual Conference of the Parties (UNFCCC).** This international treaty was signed by many countries around the world (including the United States); it 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

[11] https://www.epa.gov/renewable-fuel-standard-program/final-renewable-fuel-standards-2014-2015-and-2016-and-biomass-based

an agreement to extend the imminently expiring Kyoto Protocol. The Second Commitment Period took effect on January 1, 2013, 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 preindustrial 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 Conference of the Parties 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 reduce emissions rapidly, 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 Intended Nationally Determined Contributions (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. The agreement 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 United Nations will analyze progress on global commitments in 2023 and every 5 years thereafter. As of January 2018, 174 countries comprising over 88 percent of global GHG emissions had ratified, accepted, or approved the Paris Agreement (UNFCCC 2017). Initial GHG emissions reduction targets announced by country signatories to the Paris Agreement are expected to result in global emissions that are 3.6 gigatons lower in 2030 than projected from pre-Paris national pledges (UNFCCC 2015). Based on country pledges from the Paris Agreement, global GHG emissions in 2030 are expected to be lower than those under the highest emissions scenario (RCP8.5) but higher than those under RCP4.5 and RCP6.0 (UNFCCC 2015). While the commitments to reduce GHG emissions cannot be extrapolated into a trend (i.e., there is significant uncertainty surrounding emissions before and after 2030), they demonstrate global action to reduce the historical rate of GHG emissions growth. On August 4, 2017, the U.S. Department of State submitted a communication to the United Nations regarding the United States' intention to withdraw from the Paris Agreement as soon as it is eligible to do so. According to Article 28, the earliest that any party can effectively withdraw from the Paris Agreement is 4 years after the agreement has entered into force; thus, the earliest date that the United States can withdraw is November 4, 2020.
- **The European Union GHG Emissions Trading System.** In January 2005, the European Union Emissions Trading System commenced operation as the largest multi-country, multi-sector GHG emissions trading system worldwide (European Union 2014). The aim of the system 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 European Union 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]). In 2015, Japan's Ministry of Land, Infrastructure, Transport, and Tourism finalized new fuel economy standards for light and medium commercial vehicles sold in 2022 that are 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 proposed increasing the fleet-average fuel efficiency standard through 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).
- **China EV Targets.** China has now established a program that effectively sets quotas for PEVs and FCVs, with PEVs and FCVs expected to make up at least 10 percent of each automaker's sales in China in 2019, and 12 percent in 2020, with higher annual targets to be set for years after 2020 (McDonald 2017). China has not yet set a timetable to reach 100 percent EV sales but is expected to join other nations in phasing out sales of ICE vehicles by 2040.

8.6.4 Cumulative Impacts on Greenhouse Gas Emissions and Climate Change

8.6.4.1 Greenhouse Gas Emissions

NHTSA estimated the emissions resulting from the Proposed Action and alternatives using the methods described in Section 5.3, *Analysis Methods*.

8.6.4.2 Cumulative Impacts on Climate Change Indicators

Using the methods described in Chapter 2, *Proposed Action and Alternatives and Analysis Methods*, and Section 8.6.2, *Analysis Methods*, this section describes the cumulative impacts of the alternatives on climate change in terms of atmospheric CO_2 concentrations, temperature, precipitation, sea-level rise, and ocean pH. The impacts of this rulemaking, in combination with other reasonably foreseeable future actions, on global mean surface temperature, precipitation, sea-level rise, and ocean pH are relatively small in the context of the expected changes associated with the emissions trajectories in the GCAM scenarios. Although relatively small, primarily due to the global and multi-sectoral nature of climate change, the impacts occur on a global scale and are long-lasting.

MAGICC6 is a reduced-complexity 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 (Section 8.6.2.1, *Global Emissions Scenarios Used for the Cumulative Impact Analysis*) was used to represent the No Action Alternative in the MAGICC runs for the cumulative impacts analysis. Table 8.6.4-1 and Figure 8.6.4-1 through Figure 8.6.4-4 show the mid-range results of MAGICC model simulations for all alternatives for CO_2 concentrations and increase in global mean surface temperature in 2040, 2060, and 2100. As Figure 8.6.4-1 and Figure 8.6.4-3 show, the action alternatives would increase CO_2 concentration and temperature, but the increase would be a small fraction of the total increase in CO_2 concentrations and global mean surface temperature. As shown in Table 8.6.4-1, Figure 8.6.4-1, and Figure 8.6.4-2, the band of estimated CO_2 concentrations as of 2100 is narrow, ranging from 687.3 ppm under the No Action Alternative to 687.9 ppm under Alternative 1 and Alternative 2. 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 would lead to only small differences in climate effects.

Table 8.6.4-1. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increase, and Sea-Level Rise, and Ocean pH by Alternative[a]

	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea-Level Rise (cm)[b]			Ocean pH[c]		
Alternative	**2040**	**2060**	**2100**	**2040**	**2060**	**2100**	**2040**	**2060**	**2100**	**2040**	**2060**	**2100**
Alt. 0—No Action	472.56	546.00	687.29	1.216	1.810	2.838	22.16	35.15	70.22	8.4150	8.3609	8.2723
Alt. 1	472.67	546.29	687.90	1.216	1.812	2.841	22.17	35.17	70.28	8.4149	8.3607	8.2719
Alt. 2	472.66	546.27	687.87	1.216	1.812	2.841	22.17	35.16	70.28	8.4149	8.3607	8.2719
Alt. 3	472.66	546.26	687.83	1.216	1.812	2.840	22.16	35.16	70.28	8.4149	8.3607	8.2720
Alt. 4	472.65	546.22	687.76	1.216	1.812	2.840	22.16	35.16	70.27	8.4149	8.3607	8.2720
Alt. 5	472.62	546.17	687.64	1.216	1.811	2.840	22.16	35.16	70.26	8.4149	8.3607	8.2721
Alt. 6	472.61	546.13	687.56	1.216	1.811	2.839	22.16	35.16	70.25	8.4149	8.3608	8.2721
Alt. 7	472.59	546.08	687.44	1.216	1.811	2.839	22.16	35.16	70.24	8.4149	8.3608	8.2722
Alt. 8	472.60	546.10	687.49	1.216	1.811	2.839	22.16	35.16	70.24	8.4149	8.3608	8.2722
Increases Under Alternatives												
Alt. 1	0.11	0.28	0.62	0.001	0.001	0.003	0.00	0.01	0.06	0.0001	0.0002	0.0004
Alt. 2	0.11	0.27	0.58	0.001	0.001	0.003	0.00	0.01	0.06	0.0001	0.0002	0.0003
Alt. 3	0.10	0.25	0.55	0.000	0.001	0.003	0.00	0.01	0.05	0.0001	0.0002	0.0003
Alt. 4	0.09	0.22	0.48	0.000	0.001	0.002	0.00	0.01	0.05	0.0001	0.0002	0.0003
Alt. 5	0.07	0.16	0.35	0.000	0.001	0.002	0.00	0.01	0.04	0.0001	0.0001	0.0002
Alt. 6	0.05	0.13	0.28	0.000	0.001	0.001	0.00	0.01	0.03	0.0000	0.0001	0.0002
Alt. 7	0.03	0.07	0.15	0.000	0.000	0.001	0.00	0.00	0.02	0.0000	0.0001	0.0001
Alt. 8	0.04	0.10	0.21	0.000	0.000	0.001	0.00	0.00	0.02	0.0000	0.0001	0.0001

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] Ocean pH changes reported as 0.0000 are more than zero but less than 0.0001.
CO_2 = carbon dioxide; ppm = parts per million; °C = degrees Celsius; cm = centimeters.

Atmospheric Carbon Dioxide Concentrations

As Figure 8.6.4-1 and Figure 8.6.4-2 show, the increases in projected CO_2 concentrations under the Proposed Action and alternatives compared to the No Action Alternative amount 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 increases of CO_2 concentrations under the range of action alternatives. As shown in Figure 8.6.4-2, the increase in CO_2 concentrations by 2100 under Alternative 1 compared to the No Action Alternative is more than twice that of Alternative 7 compared to the No Action Alternative.

Figure 8.6.4-1. Atmospheric Carbon Dioxide Concentrations by Alternative

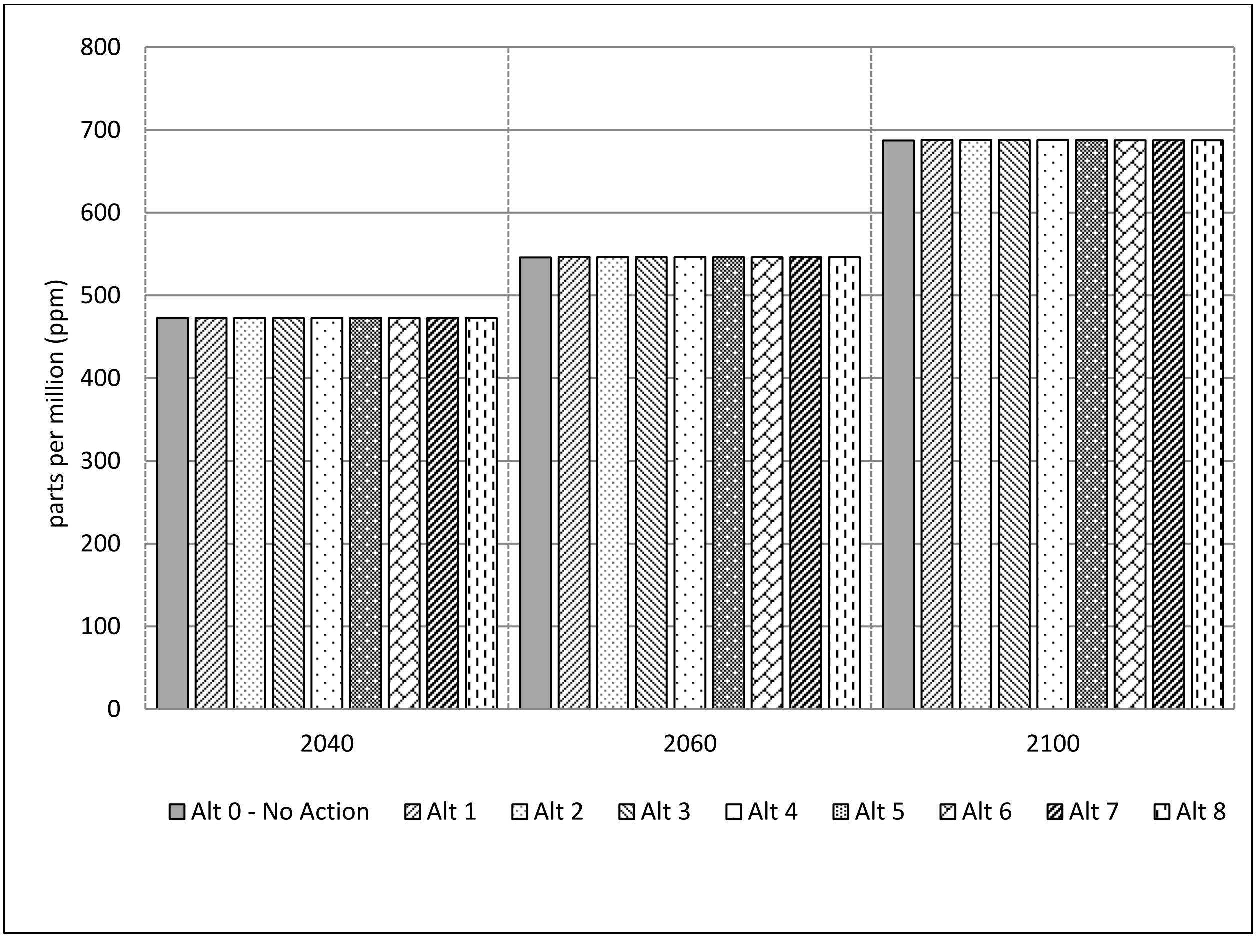
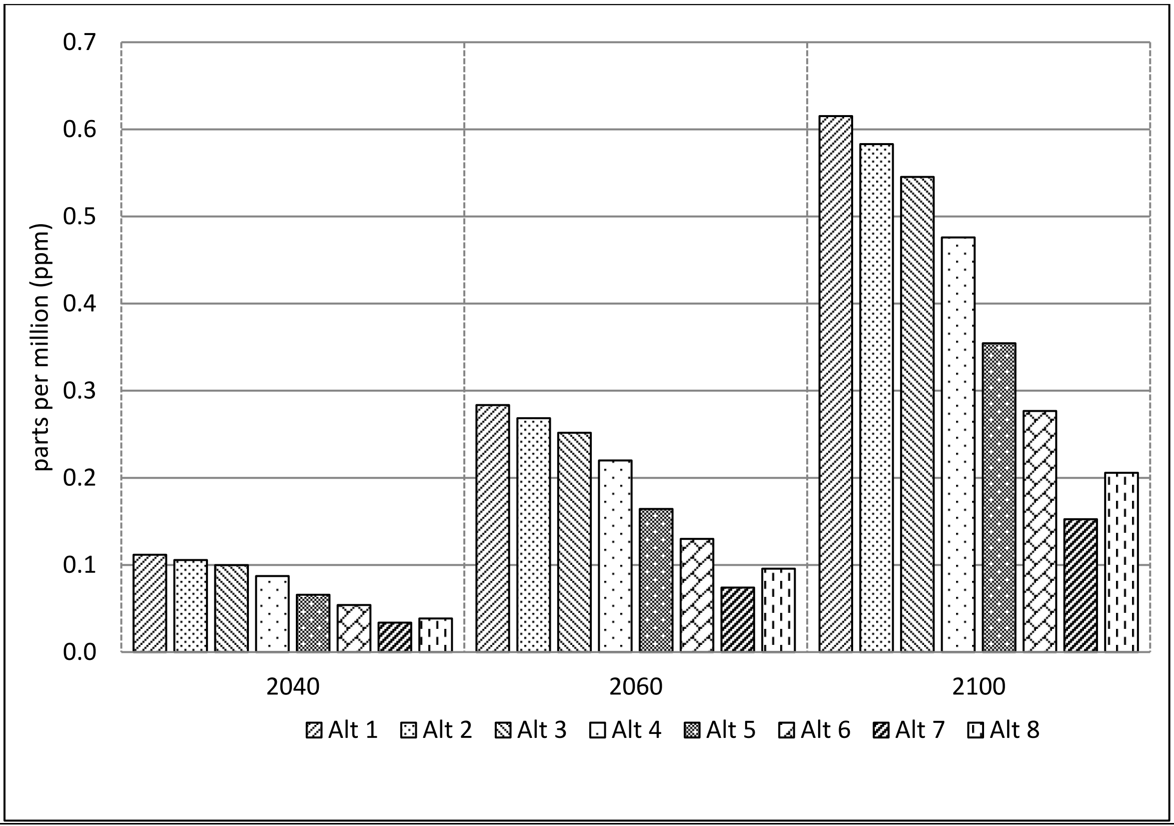


Figure 8.6.4-2. Increase in Atmospheric Carbon Dioxide Concentrations Compared to the No Action Alternative



Temperature

MAGICC simulations of mean global surface air temperature increases are shown in Figure 8.6.4-3 and Figure 8.6.4-4. 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 1.216°C (2.189°F) by 2040, 1.810°C (3.260°F) by 2060, and 2.838°C (5.108°F) by 2100.[12] The differences among the increases in baseline temperature projected to result from the action alternatives are small compared to total projected temperature increases (Figure 8.6.4-3). For example, in 2100, the increase in temperature under the action alternatives would range from approximately 0.001°C (0.002°F) under Alternative 7 to 0.003°C (0.006°F) under Alternative 1. Quantifying the changes to regional climate from this rulemaking is not possible because of the limitations of existing climate models. However, the action alternatives would be expected to increase the changes in regional temperatures roughly in proportion to the increase in global mean surface temperature. Regional changes to warming and seasonal temperatures as described in the IPCC Fifth Assessment Report are summarized in Table 5.4.1-5.

[12] 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 8.6.4-3. Global Mean Surface Temperature Increase by Alternative

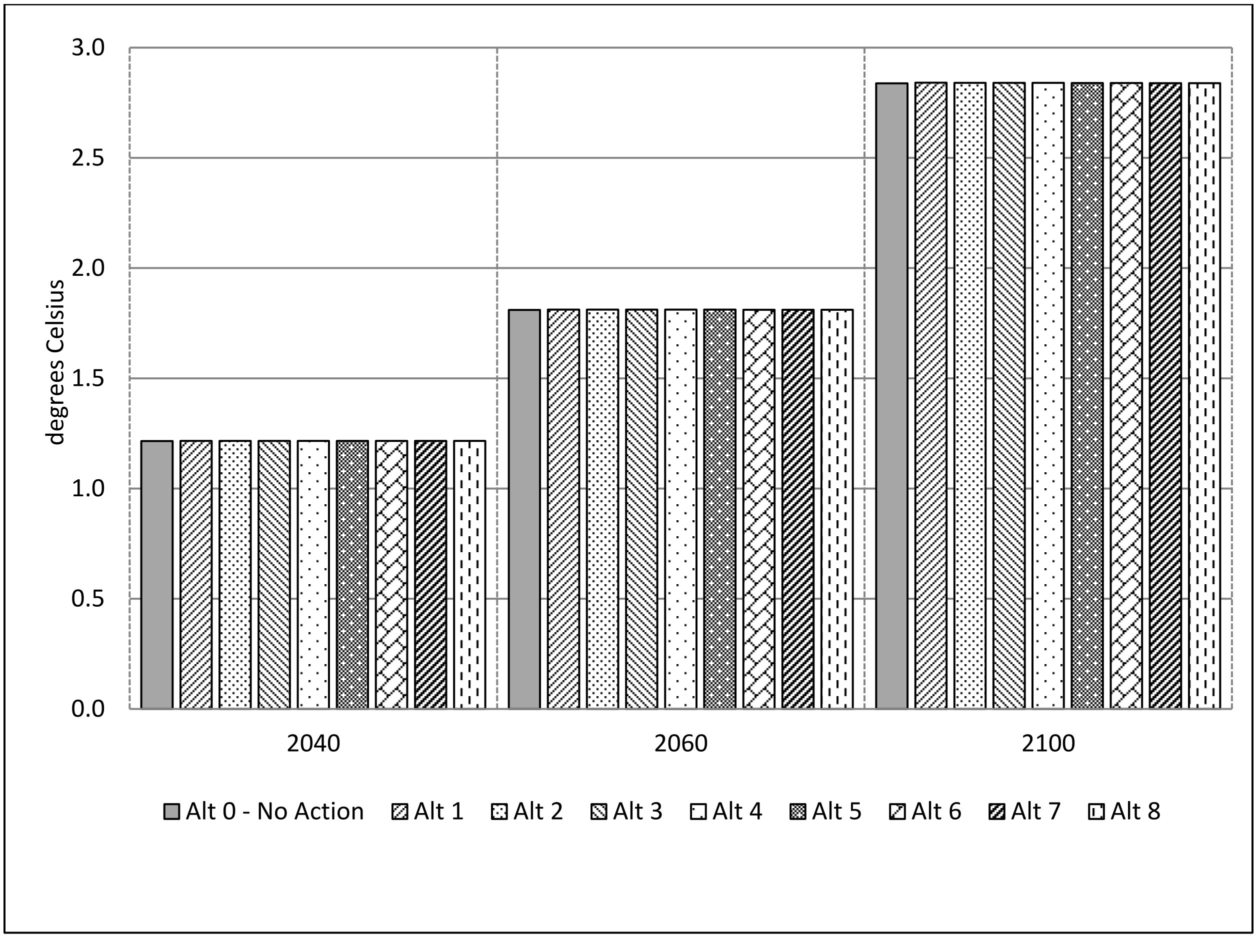
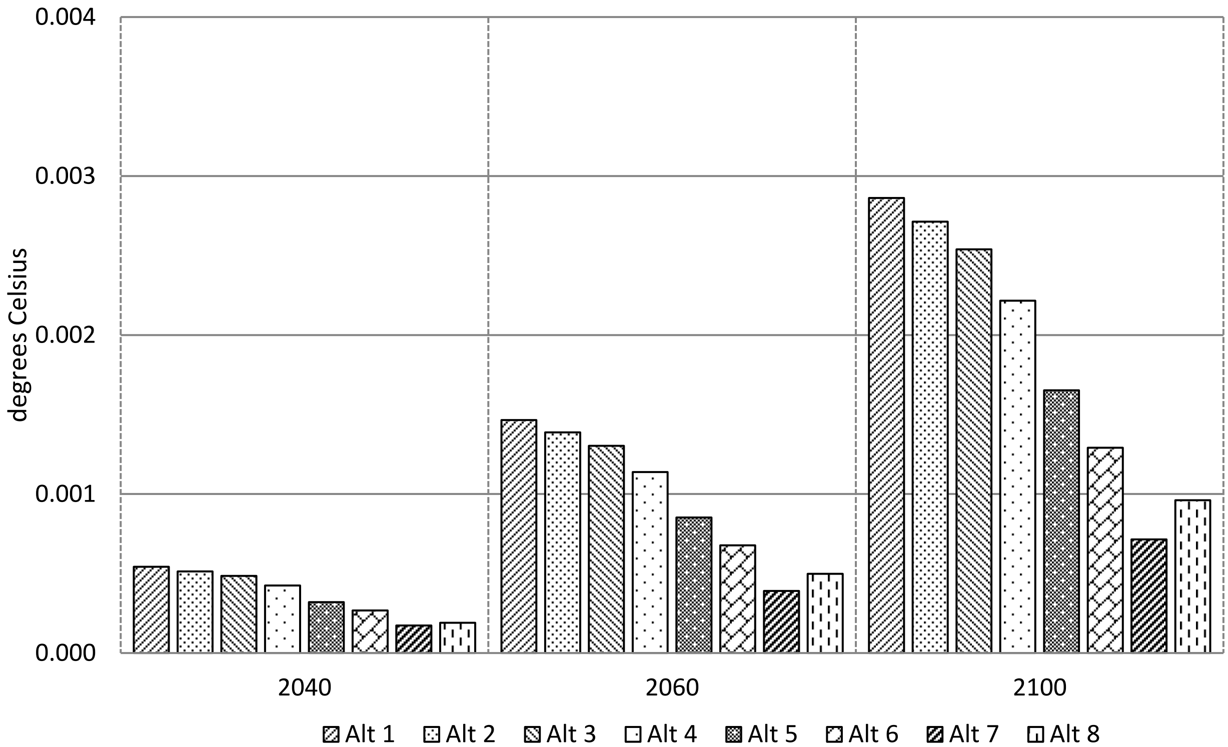


Figure 8.6.4-4. Increase in Global Mean Surface Temperature Compared to the No Action Alternative



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 5.4.2.3, *Precipitation*. Applying these scaling factors to the increase in global mean surface warming provides estimates of changes in global mean precipitation. Given that the Proposed Action and alternatives would increase temperatures slightly compared to the No Action Alternative, they also would increase predicted increases in precipitation slightly; however, as shown in Table 8.6.4-2, the increase would be less than 0.005 percent, rounded to 0.00 percent in the table.

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 8.6.4-2. Global Mean Precipitation (Percent Increase) Based on GCAM6.0 Scenario Using Increases in Global Mean Surface Temperature Simulated by MAGICC, by Alternative[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			
Alt. 0—No Action	1.216	1.810	2.838
Alt. 1	1.216	1.812	2.841
Alt. 2	1.216	1.812	2.841
Alt. 3	1.216	1.812	2.840
Alt. 4	1.216	1.812	2.840
Alt. 5	1.216	1.811	2.840
Alt. 6	1.216	1.811	2.839
Alt. 7	1.216	1.811	2.839
Alt. 8	1.216	1.811	2.839
Increase in Global Temperature (°C) Compared to the No Action Alternative[b]			
Alt. 1	0.001	0.001	0.003
Alt. 2	0.001	0.001	0.003
Alt. 3	0.000	0.001	0.003
Alt. 4	0.000	0.001	0.002
Alt. 5	0.000	0.001	0.002
Alt. 6	0.000	0.001	0.001
Alt. 7	0.000	0.000	0.001
Alt. 8	0.000	0.000	0.001
Global Mean Precipitation Increase (%)			
Alt. 0—No Action	2.04%	3.04%	4.77%
Alt. 1	2.04%	3.04%	4.77%
Alt. 2	2.04%	3.04%	4.77%
Alt. 3	2.04%	3.04%	4.77%
Alt. 4	2.04%	3.04%	4.77%
Alt. 5	2.04%	3.04%	4.77%
Alt. 6	2.04%	3.04%	4.77%
Alt. 7	2.04%	3.04%	4.77%
Alt. 8	2.04%	3.04%	4.77%
Increase in Global Mean Precipitation Increase Compared to the No Action Alternative[c]			
Alt. 1	0.00%	0.00%	0.00%
Alt. 2	0.00%	0.00%	0.00%
Alt. 3	0.00%	0.00%	0.00%
Alt. 4	0.00%	0.00%	0.00%
Alt. 5	0.00%	0.00%	0.00%

Scenario	2040	2060	2100
Alt. 6	0.00%	0.00%	0.00%
Alt. 7	0.00%	0.00%	0.00%
Alt. 8	0.00%	0.00%	0.00%

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.
[c] The increase in precipitation is less than 0.005% and thus is rounded to 0.00%.
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 that would result from the action alternatives is not possible, but the action alternatives would increase regional changes in precipitation roughly in proportion to the increase in global mean precipitation. Regional changes to precipitation as described by the IPCC Fifth Assessment Report are summarized in Table 5.4.1-5.

Sea-Level Rise

The components of sea-level rise, treatment of these components, and recent scientific assessments are discussed in Section 5.4.2.4, *Sea-Level Rise*. Table 8.6.4-1 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 70.28 centimeters (27.67 inches) under Alternative 1, for a maximum increase of 0.06 centimeter (0.02 inch) by 2100.

Ocean pH

As Table 8.6.4-1 shows, the projected decrease of ocean pH under each action alternative compared to the No Action Alternative would amount to a small fraction of the projected total decrease in ocean pH. However, the relative impact of the action alternatives is demonstrated by the decrease of ocean pH under the range of action alternatives. As shown in Table 8.6.4-1, the decrease of ocean pH by 2100 under Alternative 1 would be more than three times that of Alternative 7.

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 of three of the alternatives—the No Action Alternative, Alternative 1, and Alternative 7. This range of alternatives was deemed sufficient to assess the effect of various climate sensitivities on the results. Table 8.6.4-3 presents the results of the sensitivity analysis for cumulative impacts.

Table 8.6.4-3. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise,[a] and Ocean pH for RCP4.5 for Selected Alternatives[b]

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-Level Rise (cm)[c]	Ocean pH
		2040	2060	2100	2040	2060	2100	2100	2100
Alt. 0—No Action	1.5	454.05	494.89	510.15	0.619	0.859	1.040	31.58	8.3864
	2.0	457.30	500.90	521.85	0.793	1.114	1.389	40.80	8.3779
	2.5	460.23	506.45	533.11	0.952	1.352	1.729	50.33	8.3699
	3.0	462.88	511.57	543.93	1.097	1.573	2.059	60.04	8.3623
	4.5	469.44	524.72	573.71	1.464	2.152	2.978	89.27	8.3421
	6.0	474.49	535.31	599.95	1.752	2.627	3.797	117.62	8.3250
Alt. 1	1.5	454.16	495.16	510.68	0.619	0.860	1.042	31.61	8.3860
	2.0	457.41	501.18	522.39	0.793	1.115	1.391	40.84	8.3775
	2.5	460.35	506.73	533.67	0.952	1.353	1.732	50.39	8.3695
	3.0	463.00	511.85	544.50	1.097	1.575	2.062	60.11	8.3619
	4.5	469.56	525.01	574.32	1.464	2.153	2.982	89.37	8.3417
	6.0	474.60	535.60	600.60	1.752	2.629	3.802	117.76	8.3245
Alt. 7	1.5	454.08	494.96	510.28	0.619	0.859	1.040	31.59	8.3863
	2.0	457.33	500.97	521.98	0.793	1.114	1.389	40.81	8.3778
	2.5	460.27	506.52	533.25	0.952	1.352	1.730	50.35	8.3698
	3.0	462.92	511.64	544.07	1.097	1.573	2.060	60.06	8.3622
	4.5	469.48	524.79	573.86	1.464	2.152	2.979	89.29	8.3420
	6.0	474.52	535.38	600.11	1.752	2.627	3.798	117.66	8.3249
Increase Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.11	0.27	0.52	0.000	0.001	0.002	0.03	0.0004
	2.0	0.11	0.28	0.54	0.000	0.001	0.002	0.04	0.0004
	2.5	0.11	0.28	0.56	0.001	0.001	0.003	0.05	0.0004
	3.0	0.11	0.28	0.57	0.001	0.002	0.003	0.07	0.0004
	4.5	0.11	0.29	0.61	0.001	0.002	0.004	0.10	0.0004
	6.0	0.11	0.29	0.65	0.001	0.002	0.005	0.14	0.0004
Increase Under Alternative 7 Compared to the No Action Alternative									
Alt. 7	1.5	0.03	0.07	0.13	0.000	0.000	0.000	0.01	0.0001
	2.0	0.03	0.07	0.13	0.000	0.000	0.001	0.01	0.0001
	2.5	0.03	0.07	0.14	0.000	0.000	0.001	0.01	0.0001
	3.0	0.03	0.07	0.14	0.000	0.000	0.001	0.02	0.0001
	4.5	0.03	0.07	0.15	0.000	0.001	0.001	0.03	0.0001
	6.0	0.03	0.08	0.16	0.000	0.001	0.001	0.04	0.0001

Notes:
[a] Sea-level rise results are based on the regression analysis described in Section 5.3.3, *Methods for Estimating Climate Effects*.
[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.
ppm = parts per million; °C = degrees Celsius; CO_2 = carbon dioxide; cm = centimeters; RCP = Representative Concentration Pathways.

The use of alternative global emissions scenarios can influence the results in several ways. Emissions increases under higher emissions scenarios can lead to larger increases 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 increases 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 preindustrial levels) could affect not only projected warming but also indirectly affect projected sea-level rise, CO_2 concentration, and ocean pH. Sea level is influenced by temperature. CO_2 concentration and ocean pH are affected by temperature-dependent effects of ocean carbon storage (higher temperature results in lower aqueous solubility of CO_2).

As shown in Table 8.6.4-4 and Table 8.6.4-5, the sensitivity of simulated CO_2 emissions in 2040, 2060, and 2100 to assumptions of global emissions and climate sensitivity is low; the incremental changes in CO_2 concentration (i.e., the difference between Alternative 7 and Alternative 1) 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, Alternative 1 would have the greatest impact on CO_2 concentration in the global emissions scenario with the highest CO_2 emissions (GCAM Reference scenario), and Alternative 7 would have the least impact in the scenario with the lowest CO_2 emissions (RCP4.5) of the action alternatives. The total range of the impact of Alternative 7 on CO_2 concentrations in 2100 is roughly 0.13 to 0.19 ppm across all three global emissions scenarios. Alternative 7, using the GCAM6.0 scenario and a 3.0°C (5.4°F) climate sensitivity, would have a 0.15 ppm increase compared to Alternative 1, which would have a 0.62 ppm increase in 2100.

Table 8.6.4-4. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise,[a] and Ocean pH for GCAM 6.0[a] for Selected Alternatives[b]

	Climate Sensitivity	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[c]			Sea-Level Rise (cm)[c]	Ocean pH
Alternative	(°C for 2 × CO_2)	2040	2060	2100	2040	2060	2100	2100	2100
Alt. 0—No Action	1.5	463.33	527.73	643.45	0.694	1.005	1.506	36.94	8.2980
	2.0	466.74	534.33	658.72	0.885	1.294	1.971	47.83	8.2889
	2.5	469.80	540.41	673.33	1.058	1.562	2.415	58.97	8.2803
	3.0	472.56	546.00	687.29	1.216	1.810	2.838	70.22	8.2723
	4.5	479.39	560.37	725.55	1.611	2.456	3.998	103.79	8.2510
	6.0	484.62	571.96	759.36	1.920	2.984	5.037	136.36	8.2329
Alt. 1	1.5	463.44	528.01	644.02	0.694	1.005	1.508	36.97	8.2976
	2.0	466.85	534.61	659.31	0.885	1.295	1.973	47.87	8.2885
	2.5	469.91	540.69	673.93	1.059	1.563	2.417	59.02	8.2800
	3.0	472.67	546.29	687.91	1.216	1.812	2.841	70.28	8.2719
	4.5	479.50	560.67	726.21	1.612	2.457	4.002	103.89	8.2506
	6.0	484.74	572.26	760.07	1.921	2.986	5.042	136.49	8.2325
Alt. 7	1.5	463.36	527.80	643.59	0.694	1.005	1.506	36.95	8.2979
	2.0	466.77	534.40	658.86	0.885	1.294	1.972	47.84	8.2888
	2.5	469.83	540.48	673.48	1.058	1.563	2.416	58.98	8.2802
	3.0	472.59	546.08	687.44	1.216	1.811	2.839	70.24	8.2722
	4.5	479.42	560.45	725.71	1.611	2.456	3.999	103.82	8.2509
	6.0	484.66	572.03	759.53	1.921	2.985	5.038	136.40	8.2328
Increase Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.11	0.28	0.57	0.000	0.001	0.002	0.03	0.0003
	2.0	0.11	0.28	0.59	0.000	0.001	0.002	0.04	0.0003
	2.5	0.11	0.28	0.61	0.001	0.001	0.003	0.05	0.0004
	3.0	0.11	0.29	0.62	0.001	0.001	0.003	0.06	0.0004
	4.5	0.11	0.29	0.67	0.001	0.002	0.004	0.10	0.0004
	6.0	0.11	0.30	0.71	0.001	0.002	0.005	0.13	0.0004
Increase Under Alternative 7 compared to the No Action Alternative									
Alt. 7	1.5	0.03	0.07	0.14	0.000	0.000	0.000	0.01	0.0001
	2.0	0.03	0.07	0.14	0.000	0.000	0.001	0.01	0.0001
	2.5	0.03	0.07	0.15	0.000	0.000	0.001	0.01	0.0001
	3.0	0.03	0.07	0.15	0.000	0.000	0.001	0.02	0.0001
	4.5	0.03	0.08	0.16	0.000	0.000	0.001	0.03	0.0001
	6.0	0.03	0.08	0.17	0.000	0.001	0.001	0.03	0.0001

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.
ppm = parts per million; °C = degrees Celsius; CO_2 = carbon dioxide; cm = centimeters; GCAM = Global Change Assessment Model.

Table 8.6.4-5. Carbon Dioxide Concentrations, Global Mean Surface Temperature Increases, Sea-Level Rise,[a] and Ocean pH for GCAM Reference for Selected Alternatives[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]	Ocean pH[d]
		2040	2060	2100	2040	2060	2100	2100	2100
Alt. 0—No Action	1.5	469.61	546.10	737.48	0.741	1.128	1.890	54.03	8.2445
	2.0	473.09	553.09	755.49	0.941	1.446	2.451	70.32	8.2350
	2.5	476.22	559.52	772.69	1.123	1.738	2.981	86.60	8.2260
	3.0	479.04	565.44	789.11	1.287	2.008	3.484	102.73	8.2176
	4.5	486.00	580.62	834.28	1.699	2.707	4.868	149.48	8.1952
	6.0	491.34	592.87	874.88	2.020	3.279	6.171	193.91	8.1759
Alt. 1	1.5	469.72	546.38	738.08	0.741	1.129	1.892	41.07	8.2442
	2.0	473.20	553.38	756.11	0.942	1.447	2.453	52.78	8.2346
	2.5	476.33	559.81	773.32	1.123	1.740	2.983	64.57	8.2257
	3.0	479.15	565.73	789.76	1.288	2.010	3.487	76.34	8.2173
	4.5	486.11	580.92	835.00	1.699	2.709	4.872	111.02	8.1949
	6.0	491.46	593.18	875.61	2.020	3.281	6.176	144.82	8.1756
Alt. 7	1.5	469.64	546.17	737.63	0.741	1.128	1.891	41.05	8.2444
	2.0	473.13	553.17	755.64	0.941	1.446	2.451	52.75	8.2349
	2.5	476.25	559.59	772.84	1.123	1.739	2.982	64.53	8.2259
	3.0	479.07	565.52	789.27	1.287	2.009	3.485	76.30	8.2175
	4.5	486.03	580.70	834.45	1.699	2.707	4.869	110.96	8.1951
	6.0	491.38	592.95	875.07	2.020	3.280	6.173	144.73	8.1759
Increase Under Alternative 1 Compared to the No Action Alternative									
Alt. 1	1.5	0.11	0.28	0.60	0.000	0.001	0.002	0.03	0.0003
	2.0	0.11	0.28	0.62	0.000	0.001	0.002	0.04	0.0003
	2.5	0.11	0.29	0.64	0.000	0.001	0.002	0.05	0.0003
	3.0	0.11	0.29	0.65	0.001	0.001	0.003	0.06	0.0003
	4.5	0.11	0.30	0.72	0.001	0.002	0.004	0.09	0.0004
	6.0	0.11	0.30	0.73	0.001	0.002	0.005	0.12	0.0003
Increase Under Alternative 7 Compared to the No Action Alternative									
Alt. 7	1.5	0.03	0.07	0.15	0.000	0.000	0.000	0.01	0.0001
	2.0	0.03	0.07	0.15	0.000	0.000	0.000	0.01	0.0001

Alternative	Climate Sensitivity (°C for 2 × CO_2)	CO_2 Concentration (ppm)			Global Mean Surface Temperature Increase (°C)[b]			Sea Level Rise (cm)[c]	Ocean pH[d]
		2040	2060	2100	2040	2060	2100	2100	2100
	2.5	0.03	0.07	0.16	0.000	0.000	0.001	0.01	0.0001
	3.0	0.03	0.07	0.16	0.000	0.000	0.001	0.01	0.0001
	4.5	0.03	0.08	0.17	0.000	0.000	0.001	0.02	0.0001
	6.0	0.03	0.08	0.19	0.000	0.001	0.001	0.03	0.0001

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 RCP6.0 and RCP8.5.
[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.
ppm = parts per million; °C = degrees Celsius; CO2 = carbon dioxide; 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 8.6.4-5. In 2040, the impact would be low due primarily to the rate at which global mean surface temperature increases in response to increases in radiative forcing. In 2100, the impact would be 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 Alternative 1, the scenario with the highest global emissions of GHGs, the GCAM Reference scenario, has a higher increase in global mean surface temperature than the scenario with lowest global emissions, RCP4.5. This is due to the nonlinear and near-logarithmic relationship between radiative forcing and CO_2 concentrations. At high emissions levels, CO_2 concentrations are high; therefore, a fixed increase in emissions yields a higher increase 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 8.6.4-3 through Table 8.6.4-5. Scenarios with lower climate sensitivities have lower increases in sea-level rise; the increase in sea-level rise is lower under Alternative 1 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 would be higher under Alternative 1 than it would be under scenarios with lower climate sensitivities. Higher global GHG emissions scenarios have higher sea-level rise, but the impact of Alternative 1 would be less than in scenarios with lower global emissions. Conversely, scenarios with lower global GHG emissions have lower sea-level rise, although the impact of Alternative 1 is greater than in scenarios with higher global emissions.

The sensitivity of the simulated ocean pH to change in climate sensitivity and global GHG emissions mirrors that of global CO_2 concentrations.

8.6.5 Health, Societal, and Environmental Impacts of Climate Change

8.6.5.1 Introduction

As described in Section 5.4 *Environmental Consequences* and Section 8.6.4, *Cumulative Impacts on Greenhouse Gas Emissions and Climate Change,* ongoing emissions of GHGs from many sectors, including transportation, affect global CO_2 concentrations, temperature, precipitation, sea level, and ocean pH. This section describes how these effects can translate to impacts on key natural and human resources.

Although the action alternatives would affect growth in GHG emissions as discussed in Section 5.4 and Section 8.6.4, they alone would neither cause nor prevent climate change. Instead, they would result in marginal increases in the already anticipated increases of global CO_2 concentrations and associated impacts, including changes in temperature, precipitation, sea level, and ocean pH that are otherwise projected to occur under the No Action Alternative. NHTSA's assumption is that increases in climate effects relating to temperature, precipitation, sea level, and ocean pH would increase impacts on affected resources described in this section. However, the climate change impacts of the Proposed Action and alternatives would be too small to address quantitatively in terms of impacts on the specific resources.[13] Consequently, the discussion of resource impacts in this section does not distinguish between the alternatives; rather, it provides a qualitative review of projected impacts (where the potential incremental increases in GHG emissions would result in incremental increases in these impacts). This section also briefly describes ongoing efforts to adapt to climate change to increase the resilience of human and natural systems to the adverse risks of such change.

The health, societal, and environmental impacts are discussed in two parts: Section 8.6.5.2, *Sectoral Impacts of Climate Change*, discusses the sector-specific impacts of climate change, while Section 8.6.5.3, *Regional Impacts of Climate Change*, discusses the region-specific impacts of climate change.

8.6.5.2 Sectoral Impacts of Climate Change

This section discusses how climate change resulting from global GHG emissions (including the U.S. light-duty transportation sector under the Proposed Action and alternatives) could affect certain key natural and human resources: freshwater resources; terrestrial and freshwater ecosystems; ocean systems, coasts, and low-lying areas; food, fiber, and forest products; urban areas; rural areas; human health; human security; and stratospheric ozone. In addition, this section discusses compound events, tipping points, and abrupt climate change.

NHTSA's analysis draws largely from recent studies and reports, including the IPCC *Fifth Assessment Report* (IPCC 2013a, 2013b, 2014a, 2014c) and the Global Climate Research Program (GCRP) *National Climate Assessment* (NCA) *Reports* (GCRP 2014, 2017). The IPCC and GCRP reports, in particular, provide a comprehensive overview of the state of scientific, technical, and socioeconomic knowledge on climate change, its causes, and its potential impacts. To reflect the likelihood of climate change impacts accurately for each sector, NHTSA references and uses the IPCC uncertainty guidelines (Section 5.1.1, *Uncertainty within the IPCC Framework*). This approach provides a consistent method to define confidence levels and percent probability of a predicted outcome or impact. This is primarily applied for key IPCC and GCRP findings where IPCC or GCRP has defined the associated uncertainty with the finding

[13] Additionally, it is inappropriate to identify increases in GHG emissions associated with a single source or group of sources as the single cause of any particular climate-related impact or event.

(other sources generally do not provide enough information or expert consensus to elicit uncertainty rankings).

Recent reports from GCRP and such agencies as the National Research Council (NRC) are also referenced in this chapter. NHTSA relies on major international or national scientific assessment reports because these reports have assessed numerous individual studies to draw general conclusions about the potential impacts of climate change. This material has been well vetted, both by the climate change research community and by the U.S. government. In addition, NHTSA has supplemented the findings from these reports with recent peer-reviewed information, as appropriate.

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. More than 70 percent of the surface of the Earth is covered by water, but only 2.5 percent is fresh water. Respectively, freshwater contributions include permanent snow cover in the Antarctic, the Arctic, and mountainous regions (68.7 percent); groundwater (29.9 percent); and fresh water in lakes, reservoirs, and river systems (0.26 percent) (UNESCO 2006).

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 at the same time as continued population growth (IPCC 2014a). Although some positive impacts are anticipated, including reductions in water stress and increases in water quality in some areas because of increased runoff, the negative impacts are expected to outweigh positive impacts (IPCC 2014a, GCRP 2014).

Observed and Projected Climate Impacts

In recent decades, annual average precipitation increases have been observed across the Midwest, Great Plains, Northeast, and Alaska, while decreases have been observed in Hawaii, the Southeast and the Southwest (GCRP 2017, Walsh et al. 2014, Huang et al. 2017). Nationally, there has been an average increase of 4 percent in annual precipitation from 1901 to 2016 (GCRP 2017). According to GCRP, globally, for mid-latitude land areas of the Northern Hemisphere, annual average precipitation has *likely* increased since 1901 (GCRP 2017). For most other latitudinal zones, long-term trends in average precipitation are uncertain due to data quality, data completeness, or disagreement among available estimates (IPCC 2014c).

Detected trends in streamflow and runoff are generally consistent with observed regional changes in precipitation and temperature (IPCC 2014a). 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 2014a citing Clow 2010, Korhonen and Kuusisto 2010, Tan et al. 2011). 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 2014c).

The number and intensity of very heavy precipitation events have been increasing significantly across most of the United States (U.S. Bureau of Reclamation 2016a). According to the NCA report, river floods have been increasing in parts of the central United States (GCRP 2017). However, GCRP (2017) cites IPCC AR5 (2013a) in concluding that there are no detectable changes in observed flooding magnitude, duration, or frequency in the United States. 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 frequency and magnitude of the heaviest precipitation events is projected to increase everywhere in the United States (GCRP 2017 citing Janssen et al. 2014; U.S. Bureau of Reclamation 2016a; GCRP 2014 citing Kharin et al. 2013). 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). Across a range of emissions scenarios and models, flooding could intensify in many U.S. regions by the 2050s, even in areas where total precipitation is projected to decline (U.S. Bureau of Reclamation 2016a, 2016b).

In the United States, there is mixed information on the historical connection between climate change and drought. GRCP found that there is little evidence of a human influence on past precipitation shortages (i.e., meteorological or hydrological droughts); however, there is *high confidence* of a human influence on surface soil moisture deficits due to higher temperatures and the resultant increase in evaporation (i.e., agricultural droughts) (GCRP 2017). Globally, meteorological and agricultural droughts have become more frequent since 1950 in some regions, including southern Europe and western Africa (IPCC 2014a citing Seneviratne et al. 2012).

Dry spells are also projected to increase in length in most regions, especially in the southern and northwestern portions of the contiguous United States (EPA 2015b). 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 Southwest (GCRP 2017). Furthermore, trends of earlier spring melt and reduced snow water equivalent are expected to continue, and analyses using higher emissions scenarios project with *high confidence* that the western United States will see chronic, long-duration hydrological droughts (GCRP 2017).

Rising temperatures across the United States have reduced total snowfall, lake ice, seasonal snow cover, sea ice, glaciers, and permafrost over the last few decades (GCRP 2017, EPA 2016d citing Mote and Sharp 2016). 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 2014a citing Stoll et al. 2011), and the extent to which groundwater abstractions have already been affected by climate change is not known. Groundwater recharge impacts vary globally (IPCC 2014a citing Allen et al. 2010b, Crosbie et al. 2013b, Ng et al. 2010, Portmann et al. 2013). 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 (U.S. Bureau of Reclamation 2016b, GCRP 2017).

Globally, most observed changes of water quality attributed 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 2014a citing Paerl and Huisman 2008). For rivers, all reported impacts on water quality are 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 2014a 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.

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.

Adaptation

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. 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 planning, operational, and capital infrastructure strategies (EPA 2015c, Abt Associates 2016). Water conservation and demand management are also being promoted as important nonstructural, low-regrets approaches for managing water supply. Climate change mitigation policies, if not designed with careful attention to water resources, could increase the magnitude, spatial coverage, and frequency of water deficits given potential increased demand for irrigation water for bioenergy crops (Hejazia et al. 2015).

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 nonhuman 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). Terrestrial and freshwater ecosystems in the United States and around the world are experiencing rapid and observable changes. 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, such as marshes, swamps, and bogs.

Observed and Projected Climate Impacts

Recent global satellite and ground-based data have identified phenology[14] shifts, including earlier spring events such as breeding, budding, flowering, and migration, which have been observed in hundreds of plant and animal species (IPCC 2014a citing Menzel et al. 2006, Cleland et al. 2007, Parmesan 2007, Primack et al. 2009, Cook et al. 2012a, Peñuelas et al. 2013). In the United States from 1981 to 2010, leaf and bloom events shifted to earlier in the year in northern and western regions, but later in southern regions (EPA 2016e citing Schwartz et al. 2013). Phenological mismatches that result in unfavorable breeding conditions could cause significant negative impacts on species' breeding processes (GCRP 2014

[14] Phenology refers to the relative timing of species' life-cycle events.

citing Lawler et al. 2010, Todd et al. 2011; Little et al. 2017 citing McNab 2010, Potti 2008; Pecl et. al 2017 citing CAFF 2013, Mustonen 2015).

Species respond to stressors such as climate change by phenotypic[15] or genotypic[16] modifications, migrations, or extinction (IPCC 2014a citing Dawson et al. 2011, Bellard et al. 2012, Peñuelas et al. 2013). Changes in morphology[17] 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).

Over the past several decades, a pole-ward (in latitude) and upward (in elevation) extension of various species' ranges has been observed that may be attributable to increases in temperature (IPCC 2014a). 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). Over the 21st century, species range shifts, as well as extirpations, may 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, Stralberg et al. 2009).

IPCC concluded 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 proportion of species that are at risk (ranging from 1 to 50 percent) (IPCC 2014a). For example, regional warming puts some bird populations at risk when increased predatory populations or declines in available habitat (resulting in fewer appropriate nesting and egg-laying spots) leads to increased vulnerability of their eggs to predators (Wormworth and Mallon 2010). Additionally, an increase in phosphorus and nitrogen in freshwater resources (eutrophication) from increased agricultural runoff is probable in the Northeast, California, and Mississippi Basin, especially in areas that experience heavier or more frequent precipitation events (GCRP 2014 citing Howarth et al. 2012, Howarth et al. 2006, Sobota et al. 2009, Justić et al. 2005, McIsaac et al. 2002). The effects of eutrophication include excessive growth of algae (algal blooms), which reduce dissolved oxygen in the water, causing some plants, fish, and invertebrates to die.

In the first decade of the 21st century, net primary productivity among terrestrial systems was estimated to be 5 percent greater than preindustrial productivity, which is equivalent to increased carbon storage of about 2.6 pentagrams (1 pentagram equals 1 quadrillion or $1x10^{15}$ grams) (IPCC 2014a). This trend was attributed to increased plant growth in high latitudes (IPCC 2013a). Many studies have indicated that accelerated tree growth occurred over the 20th century (IPCC 2014a citing Briffa et al. 2008), which is associated with increased temperature that supports vegetation growth and can be associated with direct CO_2 fertilization (IPCC 2014a). Conversely, in areas experiencing extended drought (such as the western United States in 2014), water stress results in decreased tree growth (IPCC 2014a). A more intense hydrological cycle, including more frequent droughts, may reduce photosynthesis and therefore reduce ecosystem productivity and carbon storage (GCRP 2017). Alternatively, as plants gain more biomass, their net storage of carbon might be limited by nutrient availability in soils (Finzi et al.

[15] Referring to an organism's observable traits, such as color or size.

[16] Referring to an organism's genetic makeup.

[17] Referring to an organism's structural or anatomical features (e.g., egg size, wing shape, or even of the organism as a whole).

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 2014a).

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 increases water use efficiency in some plants, which can increase soil moisture content, thus mitigating 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). Reduced plant transpiration can also cause a decrease in evapotranspiration, which may trigger 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). However, an observational study indicates minimal change in transpiration from increased CO_2 due to competing forces (Tor-ngern et al. 2014). Elevated CO_2 concentrations may also affect soil microbial growth rates and their impact on terrestrial carbon pools, however, these effects are complex and not well understood (Wieder et al. 2014, Bradford et al. 2016).

Ecological tipping points[18] 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 2014a 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 warming tundra that will reduce albedo, providing a warming feedback that will result in further thawing of tundra; and the large-scale changes in Amazonian rainforests to agricultural lands, resulting in decreased local and 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 2014a citing Girardin and Mudelsee 2008, Macias and Johnson 2008, Kasischke et al. 2010, Turetsky et al. 2011, Mann et al. 2012, Girardin et al. 2013a). Cascading effects in forests are possible when fire-related changes in forest composition result in reduced capacity as a carbon sink and reduced albedo, both of which factor into further warming, putting forests at even greater risk of fire and dieback (IPCC 2014a 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, O'Halloran et al. 2012).

Adaptation

In the context of natural resource management, adaptation is about managing changes (GCRP 2014 citing Staudinger et al. 2012, Link et al. 2010, West et al. 2009). The ability or inability of ecosystems to adapt to change is referred to as adaptive capacity. There could be notable regional differences in the

[18] An ecological tipping point is described by IPCC (2014a), 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 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. Rapid rather than gradual climate change may put populations at risk of extinction before beneficial genes are able to enhance the fitness of the population and its ability to adapt (Staudinger et al. 2013 citing Hoffmann and Sgro 2011).

Some adaptation strategies include habitat manipulation, conserving populations with more genetic diversity 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. 2011, Cross et al. 2013, Schwartz et al. 2012). EPA (2016b) stresses the enhancement of natural buffers to protect and help ecosystems increase adaptive capacity. Anthropogenic stressors can compound climate change impacts, so reducing these effects, such as nutrient pollution or invasive species introduction, can bolster resilience (NPS 2016). The 2014 NCA report indicates the effectiveness of existing adaptation strategies and approaches may be significantly reduced in the face of a changing climate (GCRP 2014).

Ocean Systems, Coasts, and Low-Lying Areas

This section provides an overview of recent findings regarding observed and projected impacts of climate change on ocean systems, coasts, 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 2014a).

In general, global ocean surface temperatures have risen over the past century and have risen at a higher rate from 2000 to 2016 than from 1950 to 2016 (Blunden and Arndt 2017). IPCC concludes that ocean temperatures are *very likely* to increase in the future, with impacts on climate, ocean circulation, chemistry, and ecosystems (IPCC 2013b). From 1971 to 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 changes in ocean pH, 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 impacts on key habitats such as coral reefs and results in changes in distribution, abundance, and productivity of many marine species.

Observed and Projected Climate Impacts

Approximately 600 million people live in the Low Elevation Coastal Zone (IPCC 2014a 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 2014a citing de Sherbinin et al. 2011). Without adaptation, hundreds of millions of people may be displaced due to flooding and land loss by 2100, with the majority from eastern, southeastern, and southern Asia (Jongman et al. 2012). 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 who are less likely to be insured (GCRP 2014).

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, potentially altering coastal life and disrupting coast-dependent economic activities (GCRP 2014, IPCC 2014a citing Handmer et al. 2012, Horton et al. 2010, Hanson and Nicholls 2012, and Aerts et al. 2013).

Rising water temperatures and other climate-driven changes (e.g., salinity, acidification, and altered river flows) will affect 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 affect 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, Feder 2010). For example, 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-Guldberg et al. 2007, Frieler et al. 2013, Hughes 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).

ONOAA concluded that there is *very high confidence* that global average sea level has risen by 0.16 to 0.21 meters since 1900, with a 0.07-meter rise occurring since 1993 (Sweet et al. 2017b). GCRP notes that it is *very likely* that global average sea level will rise by 0.09 to 0.18 meter by 2030, 0.15 to 0.38 meter by 2050, and 0.3 to 1.2 meters by 2100, relative to 2000 (Sweet et al. 2017b). NOAA extends the upper limits of these estimates to a rise of 0.16 to 0.63 meter by 2050 and a rise of 0.3 to 2.5 meters by 2100 (Sweet et al. 2017a). GCRP concluded it is *extremely likely* that temperature increases account for 59 percent of the rise in global sea level during the 20th century (GCRP 2017 citing Kopp et al. 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 2014a, 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, Rotzoll and Fletcher 2013; Nicholls and Cazenave 2010). 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 experience more submergence, flooding, and erosion of beaches, sand dunes, and cliffs (IPCC 2014a).

Oceans have absorbed approximately 28 percent of the human-caused CO_2 over the last 250 years, resulting in a decrease in pH of 0.1 unit[19] since preindustrial times and an expected further decrease of from 0.3 to 0.4 unit by 2100 (Feely et al. 2009; GCRP 2014 citing NRC 2010, Sabine et al. 2004, Feely et al. 2009; Longo and Clark 2016 citing Guinotte and Fabry 2008; EPA 2016c). IPCC concluded 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 2014a). 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

[19] The pH scale is logarithmic; therefore, each whole unit decrease in pH is equivalent to a 10-fold increase in acidity.

reduces growth and survival of shellfish stocks globally (GCRP 2014 citing Tribollet et al. 2009, Wisshak et al. 2012, Doney et al. 2009b). IPCC concluded there is *high confidence* that coastal acidification will continue into the 21st century but with large, uncertain regional variation (IPCC 2014a).

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. Oxygen solubility decreases as temperatures increase, with greater sensitivity at lower temperatures. As a result, warming sea surface temperatures will decrease oxygen concentrations in the ocean, especially at high latitudes where predicted rates of warming are higher. In addition, warmer sea surface temperatures enhance stratification, which prevents oxygen-rich surface water from mixing with deeper water where hypoxia typically occurs. Stratification can also be a result of sea-level rise, which increases the overall volume of shallow coastal water that is susceptible to hypoxia (Altieri 2015). Oxygen-minimum zones have been growing and are projected to continue expanding to temperate and subpolar regions with future warming (IPCC 2014a). Models predict that oxygen levels in the oceans will continue to decline through 2100 by 2.4 to 3.5 percent under the RCP4.5 and RCP8.5 emissions scenarios, respectively, with greater losses regionally (Jewett and Romanou 2017 citing Bopp et al. 2013). 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 (Vaquer-Sunyer and Duarte 2011).

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 affect the density of water, which in turn affects 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 2014a 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).

Net primary production refers to the net flux of carbon from the atmosphere into organic matter over a given period.[20] Ocean systems provide approximately half of global net primary production. Net primary production 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 net primary production. Open-ocean net primary production is projected to reduce globally, with the magnitude of the reduction varying depending on the projection scenario (IPCC 2014a). Impacts on primary productivity vary significantly across regions. While primary productivity in the tropics and temperate zones is projected to decrease, primary productivity in high-latitude regions, particularly the Arctic, showed positive trends from 2003 to 2016 in all but one of nine regions, with statistically significant trends occurring in five regions (NOAA 2016a).

[20] Net primary production is estimated as the amount of carbon synthesized via photosynthesis minus the amount of carbon lost via cellular respiration.

Adaptation

The primary adaptation options for sea-level rise are retreat, accommodation, and protection (IPCC 2014a citing Nicholls 2011), which are all widely used around the world (IPCC 2014a citing Boateng 2010 and Linham and Nicholls 2010). Retreat allows the impacts of sea-level rise to occur unobstructed as inhabitants pull back from inundated coastlines. Accommodation is achieved by increasing the flexibility of infrastructure and adjusting the use of at-risk coastal zones (IPCC 2014a). Protection is the creation of barriers against sea intrusion with replenished beaches and seawalls. Ecosystem-based protection strategies, which include the protection and restoration of relevant coastal natural systems (IPCC 2014a citing Schmitt et al. 2013), oyster reefs (IPCC 2014a citing Beck et al. 2011), and salt marshes (IPCC 2014a citing Barbier et al. 2011) are increasingly attracting attention (IPCC 2014a citing Munroe et al. 2011).

Advances have 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 integrating natural landscape features with built infrastructure (green and gray infrastructure[21]) to reduce stormwater runoff and wave attack, constructing seawalls around wastewater treatment plants and pump stations, pumping effluent to higher elevations as sea levels rise, pumping freshwater into coastal aquifers to mitigate salt water infiltration, developing flood-proof infrastructure, relocation of coastal infrastructure away from the coast, and relocation of communities away from high-hazard areas (GCRP 2014). Some examples of ocean adaptation include reducing overfishing, establishing protected areas, and conserving habitat to increase resilience; culturing acid-resistant strains of shellfish; oyster reef and mangrove restoration; coral reef restoration and protection; and developing alternative livelihood options for marine food-producing sectors (GCRP 2014).

Food, Fiber, and Forest Products

Increases in atmospheric CO_2, combined with rising temperatures and altered precipitation patterns, have begun to affect both agricultural and forest systems (Walthall et al. 2013, GCRP 2014, IPCC 2014c, USDA 2015, USFS 2016, FAO 2015, GCRP 2015). These impacts are expected to become more severe and to affect food security (FAO 2015, GCRP 2015).

Observed and Projected Climate Impacts

Climate disruptions to agricultural production have increased over the past 40 years and are projected to further increase over the next 25 years. Crop and livestock production projections indicate that climate change effects through 2030 will be mixed (IPCC 2014a, Walthall et al. 2013); however, most predictions for climate change impacts on crop yields by 2050 are negative (Nelson et al. 2014, IPCC 2014a, Müller and Robertson 2014). Currently, yields for some crops are increasing; however, climate change could be diminishing the rate of these increases, inducing a 2.5 percent decrease in yield growth rates per decade (GCRP 2015 citing Porter et al. 2014). Generally, yields and food security are at greater risk in poor, low-latitude countries (FAO 2015, GCRP 2015).

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

[21] 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.

scales (GCRP 2014, USDA 2015). Bench- and field-scale experiments have found that over a certain range of concentrations, greater CO_2 levels have a fertilizing impact on plant growth (e.g., Long et al. 2006, Schimel et al. 2000) with considerable variability among regions and species (McGrath and Lobel 2013). However, climate change is projected to cause multiple abiotic (nonliving) stressors (such as temperature, moisture, extreme weather events), and biotic (living) stressors (such as disease, pathogens, weeds and insects) on crop production. (Thornton et al. 2014, IPCC 2014a, GCRP 2014, GCRP 2015, GCRP 2017). Increased frequency and intensity of extreme weather events (including extreme heat, precipitation, and storm events) is expected to negatively influence crop, livestock, and forest productivity and increase the vulnerability of agriculture and forests to climate risks (Walthall et al. 2013, GCRP 2014, IPCC 2014a, USDA 2015, EPA 2016c, USFS 2016). Additionally, climate change is projected 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 crops, livestock, and forests (Walthall et al. 2013, GCRP 2014). Livestock are vulnerable as climate change is affecting the nutritional quality of pastures and grazing lands; affecting the production, availability, and price of feed-grains; stressing animals; hurting overall animal wellbeing (i.e., animal health, growth, and reproduction and distribution of animal diseases and pests); and decreasing livestock productivity (e.g., meat, milk, and egg production) (IPCC 2014a; IPCC 2014a citing André et al. 2011, Renaudeau et al. 2011; GCRP 2015; GCRP 2014 citing Rötter and Van de Geijn 1999, Nardone et al. 2010, Walthall et al. 2013, and West 2003). Overall, climate change is predicted to negatively affect livestock on almost all continents (IPCC 2014a).

Studies have concluded that climate change is affecting aquatic ecosystems, including marine and freshwater fisheries (IPCC 2014a, Groffman et al. 2014). 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 2014a). Fisheries are affected by increases in ocean temperatures resulting in many marine fish species migrating to deeper or colder water, additional stress to already strained coral reefs, and an expansion in warm freshwater habitats and a shrinkage of cool- and cold freshwater habitats (IPCC 2014a, NOAA 2015a). Overall, each 1°C increase in temperature is projected to decrease global potential catches by 3 million metric tons (Cheung et al. 2016).

Climate change threatens forests by increasing tree mortality and forest ecosystem vulnerability due to fire, insect infestations, drought, disease outbreaks, and extreme weather events (Joyce et al. 2014, IPCC 2014a, USFS 2016). Currently, tree mortality is increasing globally due in part to high temperatures and drought (IPCC 2014a). IPCC concludes 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 2014a). However, due to the lack of models and limited long-term studies, projections of global tree mortality are currently highly uncertain (IPCC 2014a 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 (GCRP 2017, Thornton et al. 2014, IPCC 2014a, GCRP 2014, IPCC 2014a citing Allen et al. 2010a). A dramatic increase in the area burned by wildfire is projected in the contiguous United States through 2100, especially in the West (EPA 2015b, Halofsky et al. 2017). Tree species are predicted to shift their geographic distributions to track future climate change (Zhu et al. 2014, USFS 2016).

IPCC concludes that 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 2014a). Excess carbon sequestered by intact and newly growing forests appears to have stabilized in recent years (IPCC 2014a 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 affect the rate of CO_2 uptake in the future (Joyce et al. 2014, IPCC 2014a 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 2014a).

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 2014a citing Vermeulen et al. 2012). Food security comprises four key components: production; processing, packaging, and storage; transportation; and utilization and waste (GCRP 2014 citing FAO 2001), all of which are closely tied to poverty (IPCC 2014a). 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). Many of these impacts are expected to be negative, including decreasing production yields; harming pollinators; increasing costs and spoiling during processing, packaging, and storage; inhibiting water, rail, and road transportation; and increasing food safety risks (GCRP 2015, Giannini et al. 2017).

Currently, the vast majority of undernourished people live in developing countries (IPCC 2014a). Both due to the nature of the direct impacts and the means to implement adaptation strategies, climate change poses the greatest food security risks to poor and tropical region populations, and the least risk to wealthy, temperate, and high-latitude region populations (GCRP 2015, FAO 2015). 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. Import demand is expected to increase for developing nations lacking advanced technologies and practices and producing low agricultural yields (GCRP 2015).

Adaptation

Over the past 150 years, the agricultural and forestry sectors have demonstrated an impressive capacity to adapt to a diversity of growing conditions amid dynamic social and economic changes (Walthall et al. 2013, Joyce et al. 2014, FAO 2015, GCRP 2015). 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 2014a). 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 are not expected to buffer the impacts of climate change sufficiently (GCRP 2014).

To minimize these impacts, a variety of resilience actions can be implemented, including management and policy, engineering, and insurance responses. Management practices associated with sustainable agriculture, such as diversifying crop rotations and crop varieties, 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). Furthermore, the use of heat-tolerant and other adaptively advantageous varieties of crops can aid in yield increases in the face of climate change (Zhang and Zhao 2017).

Enhancing genetic resources via genetic modification and improved breeding systems also has great potential to enhance crop resilience (GCRP 2015 citing Jacobsen et al. 2013, Lin 2011).

For livestock, adaptive capacity is limited by high costs and competition. Cooling strategies are not always economically feasible due to high infrastructure and energy demands (GCRP 2015). Furthermore, increased shade and moisture can heighten pathogen risk (Fox et al. 2015). Irrigation strategies to improve feed quality and quantity could also be limited by competition with other water users, especially in arid climates (GCRP 2015 citing Elliott et al. 2014). To enhance resilience against increased pathogen risk, adaptation strategies include no-regrets strategies, disease surveillance and response, disease forecast capacity, animal health service delivery, eradication of priority diseases, increased diversification and integration of livestock with agriculture, breeding resilient animals, and monitoring impacts of land-use change on disease (Grace et al. 2015). Fisheries have developed a number of adaptation practices as well. For example, NOAA's Climate Science Strategy (2015b) sets forth the objective of designing adaptive decision processes to enable fisheries to enhance fishery resilience.

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 (Walthall et al. 2013, Joyce et al. 2014). 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). 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 and Swanston 2012). Ultimately, maintaining a diversity of tree species could become increasingly important to maintain the adaptive capacity of forests (Duveneck et al. 2014). Carbon sequestration losses can be mitigated using sustainable land-management practices (GCRP 2015 citing Branca et al. 2013).

In terms of food security, global undernourishment dropped from 19 percent in 1990 through 1992 to 11 percent in 2014 (GCRP 2015). However, it is questionable whether this progress will continue given challenges posed by climate change (GCRP 2015). Developing and implementing new agricultural methods in low-yield regions, 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. 2013, Ericksen et al. 2009, Misselhorn et al. 2012, Godfray et al. 2010, and FAO 2011; GCRP 2015). Ultimately, adaptation will 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).

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 more than half of the global population, and this percentage continues to increase every year (IPCC 2014a citing UN DESA Population Division 2013, World Bank 2008). In the United States, approximately 80 percent of the population lives in metropolitan areas[22] (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 2014a citing UN DESA Population Division 2013, World Bank 2008). However, definitions of urban centers and their

[22] 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).

boundaries vary greatly between countries and between various pieces of academic literature (IPCC 2014a).

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 2014a 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 2014a citing IFRC 2010, UNISDR 2009, and UNISDR 2011).

Observed and Projected Climate Impacts

The risks of climate change to urban communities and their populations' health, livelihood, and belongings are increasing. Such risks include 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 2014a). It cannot be assumed that climate change impacts will be the same or even similar in different cities (Silver et al. 2013). In addition, certain population groups may be more directly affected by climate change than other groups. 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 2014a; Cutter et al. 2014; GCRP 2014 citing Bates and Swan 2007, NRC 2006, and Phillips et al. 2009).

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 2014a). This could lead to increased health impacts, air pollution, and energy demand, disproportionately affecting low-income, young, and elderly populations (IPCC 2014a citing Hajat et al. 2010, Blake et al. 2011, Campbell-Lendrum and Corvalan 2007, and Lemonsu et al. 2013; IPCC 2014b citing Akbari et al. 2016). Urbanization, through increased impermeable surfaces and microclimatic changes, can also increase flooding. Climatic trends, such as increased frequency of extreme precipitation and sea-level rise, will stress existing flood infrastructure (GCRP 2017).

Drought and reduced snowpack 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. Changes in precipitation due to climate change could create water demand conflicts between residential, commercial, agricultural, and infrastructure use (IPCC 2014a citing Roy et al. 2012 and Tidwell et al. 2012). 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 2014a 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 2014a). Increased eutrophication from 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 (Baron et al. 2013).

In developed and developing countries, stormwater systems will be increasingly overwhelmed by extreme short-duration precipitation events if they are not upgraded (IPCC 2014a 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).

Climate change will have direct impacts on both the production and the demand side of the energy system by increasing risk of direct physical damage to generation as well as transmission and distribution systems, reducing the efficiency of water cooling for large thermoelectric electricity generating facilities, changing hydropower and wind power potential, and changing demands for heating and cooling in developed countries (GCRP 2014; IPCC 2014a citing Mideksa and Kallbekken 2010; DOE 2015a). Many power supply facilities such as power plants, refineries, pipelines, transmission lines, substations, and distribution networks are located in coastal environments and are thus subject to direct physical damage and permanent and temporary flooding from sea-level rise, higher storm surge and tidal action, increased coastal erosion, and increasingly frequent and intense storms and hurricanes (GCRP 2014, DOE 2015a citing CIG 2013, GCRP 2014). They may also be negatively impacted by the vulnerability of transportation systems that provide feedstocks such as coal (EIA 2017f, DOE 2015a citing DOE 2013c; Ingram et al. 2013).

Climate change impacts that decrease the reliability of 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 2014a citing Finland Safety Investigations Authority 2011, Halsnæs and Garg 2011, Hammer et al. 2011, and Jollands et al. 2007). Oil and gas availability for transportation in the United States would also be affected by increased energy demand in global markets as well as by climate change events. For example, DOE (2015a) concluded that 9 percent of U.S. refining capacity could be exposed to sea-level rise and storm surge in 2050 (assuming 23 inches of sea level rise and a Category 3 storm), and strategic petroleum reserves may be exposed to flooding during lower-intensity storms.

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 2014a 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 2014). 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 2014a citing Zimmerman and Farris 2010 and Larsen et al. 2008).

Housing in urban areas is one of the pieces of infrastructure most heavily affected by extreme weather events such as cyclones and floods (IPCC 2014a 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 2014a citing UNISDR 2011). Increased weather variability, including warmer temperatures, changing precipitation patterns, and increased humidity, accelerates the deterioration of common housing building materials (IPCC 2014a 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 2014a citing Haines et al. 2013).

Climate change will also affect urban public services such as healthcare and social care services, education, police, and emergency services (IPCC 2014a citing Barata et al. 2011). 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 2014a) and changes in air quality (IPCC 2014a citing Athanassiadou et al. 2010); however, impacts of climate change on air quality in particular locations are highly uncertain (IPCC 2014a citing Jacob and Winner 2009 and Weaver et al. 2009).

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 2014a). 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 2014a). Embedding adaptation into existing plans and decision-making processes (e.g., multi-hazard mitigation plans, long-term water plans, permitting review processes) helps to institutionalize adaptation (Aylett 2015).

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 2014a). Additionally, there are emerging synergistic options for urban adaptation measures that also deliver GHG emissions reductions co-benefits (IPCC 2014a).

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 2014a 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. In general, IPCC and this EIS accept the definitions of urban and rural used by individual countries and individual academic authors in their work.

Rural areas account for almost half of the world’s total population and an even greater percentage of people in developing countries (IPCC 2014a 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, USDA 2012). In the United States, modern rural populations are generally more vulnerable to climate change impacts due to various socioeconomic factors (e.g., age, income, education) (GCRP 2014).

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 2014a). These rural vulnerabilities also have the potential to affect urban areas significantly; 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).

Observed and Projected Climate Impacts

Rural livelihoods are less diverse than their urban counterparts are and are frequently dependent on natural resources that have unknown future availability such as agriculture, fishing, and forestry (IPCC 2014a, GCRP 2014). In addition, communities that rely on mining and extraction will be affected by changes in the water, energy, and transportation sectors (IPCC 2014a, GCRP 2014). Due to this lack of economic diversity, climate change will place disproportionate stresses on the stability of these rural 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 2014a citing Morton 2007, Anderson et al. 2010).

Events that have a negative impact on rural areas include tropical storms that can lead to sudden flooding and wind damage, droughts and temperature extremes that can increase water scarcity and thus kill livestock and affect agricultural yields (IPCC 2014a citing Handmer et al. 2012, Ericksen et al. 2012), inland flooding, and wildfires (Hales et al. 2014).

Rural areas frequently depend on groundwater extraction and irrigation for local agriculture (IPCC 2014a citing Lobell and Field 2011). Reduced surface water would 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 2014a, GCRP 2014). For example, 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 (GCRP 2014).

For more information on climate impacts on livestock, fisheries, and agriculture, see the section entitled *Food, Fiber, and Forest Products*. Nonfood crops and high-value food crops such as cotton, rice, corn, wheat, wine grapes, beverage crops (coffee, tea, and cocoa), and other cash crops contribute to an important source of income to rural locations. While these crops tend to receive less study than staple food crops (IPCC 2014a), negative impacts of climate change on a variety of crop types have already been documented (GCRP 2014).

Impacts of climate change on rural infrastructure are similar to those in urban areas (see the section entitled *Urban Areas*) but frequently there is less redundancy in the system so assets are more vulnerable to hydroclimatic events (GCRP 2014, IPCC 2014a citing NRC 2008). Rural communities are becoming more connected to urban ones, but human migration from rural to urban areas is not necessarily any greater due to climate change than under regular conditions. This diverges from previous assumptions of increased migration (IPCC 2014a). Migration will increase following extreme events that lead to the desertion of local communities (e.g. extreme storms), but migration from slow environmental degradation (e.g., sea level rise) is anticipated to be minimal. Generally, more migration is linked to additional stressors such as political instability and socioeconomic factors (IPCC 2014a citing van der Geest 2011). It is possible that factors such as increased temperatures and natural disasters will spur migration, but the underlying force may be the adverse consequences of climate change on agriculture (Bohra-Mishra et al. 2017).

There is a strong link between biodiversity, tourism, rural livelihoods, and rural landscapes in both developed and developing countries (IPCC 2014a 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 2014a citing Lal et al. 2011). Coastal tourism is vulnerable to cyclones and sea-level rise (IPCC 2014a citing Klint et al. 2012 and Payet and Agricole 2006) as well as beach erosion and saline intrusion (IPCC 2014a). Nature-based tourism may be affected by declining biodiversity and harsher conditions for trekking and exploring (IPCC 2014a citing Thuiller et al. 2006 and Nyaupane and Chhetri 2009). Winter sport tourism may be affected by declining snow packs and precipitation falling more frequently as rain rather than snow due to warmer temperatures (IPCC 2014a).

Adaptation

Rural adaptation will build on community responses to past climate variability; however, this could not be enough to allow communities to fully cope with climate impacts (IPCC 2014a). 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 2014a citing Fisher et al. 2010). Successful adaptation should allow for the development of long-term strategies that not only respond to climate events but also minimize future vulnerabilities (IPCC 2014a 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 2014a citing Nielsen et al. 2012, Hassan 2010, and Eriksen and O’Brien 2007).

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. Effects on human health 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.

Observed and Projected Climate Impacts

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 2016i).

Many types of extreme events related to climate change cause disruption to infrastructure—including power, heating, ventilation and air conditioning systems, water, transportation, and communication systems—that are essential to maintaining access to health care and emergency response services that safeguard human health (EPA 2016i, GCRP 2016). The damage caused by extreme events can disrupt transportation and access to health services, which exacerbates health conditions of those chronically sick (GCRP 2016).

One direct way that climate change is projected to affect human health is through increasing incidence of extreme heat, which is the leading source of weather-related deaths in the United States (Nahlik et al. 2017). Higher than usual temperatures can cause heat exhaustion and heat stroke, and exacerbate other cardiovascular and pulmonary conditions (Tianqi et al. 2017 citing Borden and Cutter 2008, Bouchama et al. 2007, and Wilker et al. 2012). In general, those with pre-existing conditions are more vulnerable to heat-related illness (Kuehn and McCormick 2017). 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 2016i, GCRP 2016). Pregnant women and their fetuses are particularly vulnerable to the impacts of heat exposure because their thermoregulatory abilities are limited. Increased heat events could increase preterm birth, decrease birth weights, and increase the rate of stillbirths (Kuehn and McCormick 2017).

The reduction in cold-related deaths has not been studied as thoroughly as heat-related deaths, although such events have become less frequent and intense, and they are expected to continue to decrease (GCRP 2016). 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 2016i; EPA 2015b; IPCC 2014a citing Ebi and Mills 2013, Kinney et al. 2012; Medina-Ramón and Schwartz 2007; GCRP 2014 citing Yu et al. 2011 and Li et al. 2013; Hajat et al. 2014; GCRP 2016 citing Mills et al. 2012, Deschênes and Greenstone 2011, Barreca 2012, and Honda et al. 2014).

Although CO_2 emissions do not directly affect air quality, increased temperatures and related climate changes due to emissions of CO_2 and other GHGs could increase the formation of ozone and PM2.5 and affect their dispersion and transport, affecting ozone and PM2.5 concentrations. Climate change could increase ground-level concentrations of ozone or particulate matter in some locations, thus degrading air quality and negatively affecting human health (Section 4.1.1.1, *Health Effects of Criteria Pollutants*), as well as being associated with developmental problems such as childhood attention deficit hyperactivity disorder (Perera 2017 citing Newman et al. 2013, Perera et al. 2014). Climate change may result in meteorological conditions more favorable for the formation of ozone, including higher temperatures, less relative humidity, and altered wind patterns (Jacob and Winner 2009, GCRP 2016). Ozone production could increase with rising temperatures, especially in urban areas (IPCC 2014a citing Chang et al. 2010, Ebi and McGregor 2008, Polvani et al. 2011, and Tsai et al. 2008). These climate-driven increases in ozone could cause premature deaths, hospital visits, lost school days, and acute respiratory symptoms (GCRP 2016).

As with ozone, climate change is expected to alter several meteorological factors that affect PM2.5, including precipitation patterns, wind patterns and atmospheric mixing, and humidity, although there is less consensus regarding the effects of meteorological changes on PM2.5 than on ozone (Jacob and Winner 2009, GCRP 2016 citing Dawson et al. 2014). Because of the strong influence of changes in precipitation and atmospheric mixing on PM2.5 levels and because of the high variability in projected changes to those variables, it is not yet clear whether climate change will lead to a net increase or decrease in PM2.5 levels in the United States (GCRP 2016 citing Dawson et al. 2014, Fiore et al. 2012, Penrod et al. 2014, Tai et al. 2012, Val Martin et al. 2015, Dawson et al. 2009, Trail et al. 2014). Overall, however, eastern, midwestern, and southern states are projected to experience degraded air quality associated with climate change (EPA 2015b, GCRP 2016). Because the impact of the Proposed Action and alternatives on global average temperature and other climate indicators is expected to be minimal, the impact of the GHG emissions from the Proposed Action and alternatives on ozone and air quality is also expected to be minimal.

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 2016i, GCRP 2016). Climate change could also affect air quality through 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 2014a citing IPCC 2012). Combined with higher air temperatures, this could foster the growth of fungi and molds, diminishing indoor air quality, particularly in impoverished communities (GCRP 2014 citing Fisk et al. 2007, Institute of Medicine 2011, Mudarri and Fisk 2007, and Wolf et al. 2010).

Increased temperatures and CO_2 concentrations can shift or extend plant growing seasons, including those of plants that produce allergens and pollen (EPA 2016i, 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, Ziska et al. 2011, and Hjort et al. 2016). These effects already occur worldwide and are projected to continue with climate change (D'Amato et al. 2013, GCRP 2014, IPCC 2014a). Increases in pollen and other aeroallergens can exacerbate asthma and other health problems such as conjunctivitis and dermatitis (EPA 2016i, IPCC 2014a citing Beggs 2010). Exposure to air pollutants such as increased ozone or particulate matter levels could also exacerbate the effects of aeroallergens (GCRP 2016 citing Cakmak et al. 2012). Increases in aeroallergens 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).

Climate—both temperature and precipitation—can influence the growth, survival, and persistence of water- and food-borne pathogens (EPA 2016i, IPCC 2014a). 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 2016i, GCRP 2016). Diarrheal disease rates are also linked to temperatures (IPCC 2014a). More frequent and intense rainfall and storm surge events could lead to combined sewer overflows that can contaminate water resources (EPA 2016i, IPCC 2014a 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; GCRP 2016). Rising water temperatures could also increase the growth and abundance of pathogens in coastal environments that cause illnesses and deaths from both water contact and ingestion of raw or undercooked seafood. Changes in ocean pH may also increase virulent strains of pathogens prevalent in seafood, particularly because acidification can increase the proliferation of microbes that affect shellfish, whose immune responses and shells are weakened, making them more susceptible to infection (NIH 2010). Climate change-induced drought may increase the spread of pests and mold that can produce toxins dangerous to consumers (NIH 2010 citing Gregory et al. 2009). 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). In 2015, an estimated 688 million illnesses and 499,000 deaths of children under 5 years of age were attributed to diarrheal diseases worldwide, making it the second leading cause of death for this age group (Kotloff et al. 2017 citing GBD 2015).

Climate change, particularly changes in temperatures, could change the range, abundance, and disease-carrying ability of disease vectors such as mosquitoes or ticks (EPA 2016i, IPCC 2014a, and GCRP 2016). This, in turn, could affect the prevalence and geographic distribution of diseases such as Rocky Mountain spotted fever, plague, tularemia, malaria, dengue fever, chikungunya virus, Lyme disease, West Nile virus, and Zika virus in human populations (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). 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, Deichstetter 2017). Climate change could also alter temperature, precipitation, and cloud cover, which can affect 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 (IPCC 2014a citing van der Leun et al. 2008, Correa et al. 2013, Belanger et al. 2009).

Climate change can influence mental health. People can 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 2016i). Extreme weather conditions can increase stress population-wide, which can exacerbate preexisting mental health problems and even cause such conditions (EPA 2016i, IPCC 2014a). 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 2016i, GCRP 2016 citing Osofsky et al. 2011, Schulte et al. 2016).

Environmentally motivated migration and displacement may lead to disruption of social ties and community bonds, which may negatively affect mental health, for both those displaced and those who stay behind (Torres and Casey 2017). Stress, induced by climate change or other factors, can also result in pregnancy-related problems such as preterm birth, low birth weight, and maternal complications (Harville et al. 2009, GCRP 2014 citing Xiong et al. 2008, GCRP 2016 citing Sheffield and Landrigan 2011 and Rylander et al. 2013). Heat can also affect mental health and has been known to increase suicide rates, dementia, and problems for patients with schizophrenia and depression (EPA 2016i; 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; GCRP 2016 citing Ruuhela et al. 2009, Dixon et al. 2007, Qi et al. 2009, and Preti et al. 2007).

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).

Adaptation

IPCC (2014a) characterizes three tiers of adaptation: 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 2014a). Transitional adaptation refers to policies and measures that incorporate climate change considerations, such as vulnerability mapping, while transformational adaptation involves more drastic system-wide changes and has yet to be implemented in the health sector (IPCC 2014a).

The public health community has identified several potential adaptation strategies to reduce the risks to human health from climate change. The Centers for Disease Control and Prevention has established the Building Resilience against Climate Effects Framework, which can help health officials assess how climate impacts could affect disease burdens and develop a Climate and Health Adaptation Plan. The framework aligns with the Climate-Ready States and Cities Initiative, which, as of June 2018, is working with 16 states and two cities to project future health impacts and develop programs to address them.

The program provides resources for states, cities, and municipalities to develop their own climate and health adaptation plans, including concept documents, toolkits, webinars, and data resources.

In terms of specific adaptation measures, early warning programs 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). A local adaptation strategy may include opening a community cooling center during heat waves to accommodate vulnerable and at-risk populations (Nayak et al. 2017). In the long term, 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 2012b; Boumans et al. 2014; McDonald et al. 2016). 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).

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 2014a). 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 2014a). Climate change may have far-reaching impacts on existing problems, such as poverty, social tensions, environmental degradation, ineffectual leadership, and weak political institutions both nationally and internationally (DOD 2015).

Observed and Projected Climate Impacts

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 2014a). In particular, climate change will affect those whose livelihoods depend on natural resources (Brzoska and Frohlich 2015, Reyer et al. 2017). 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 2014a citing Carter et al. 2007, Leary et al. 2008, Peras et al. 2008, Paavola 2008, and Tang et al. 2009). Populations that are most at risk include the urban poor and the rural and indigenous communities whose livelihoods are highly dependent upon natural resources (GCRP 2014).

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 2014a citing Crate and Nuttall 2009 and Rybråten and Hovelsrud 2010; GCRP 2014 citing Lynn et al. 2013). Many anthropological studies indicate that further significant changes in the natural resource base would negatively affect indigenous cultures (IPCC 2014a citing Crate 2008, Gregory and Trousdale 2009, and Jacka 2009). For example, climate change is causing changes in the range and abundance of culturally important plant and animal species, reducing the availability of 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 addition, traditional practices are already facing multiple stressors, such as changing socioeconomic conditions and globalization, which undermine their ability to adapt to climate change (IPCC 2014a citing Green el al. 2010). Climate change can also cause loss of land and displacement, such as in small island nations or coastal communities, which have well-documented negative cultural and well-being impacts (IPCC 2014a citing Bronen 2011, Johnson 2012, Arnall 2013, Bronen 2010, Bronen and Chapin 2013, and Cunsolo-Willox et al. 2012, 2013).

The efficacy of traditional practices can be eroded “when governments relocate communities” (IPCC 2014a citing Hitchcock 2009, McNeeley 2012, and Maldonado et al. 2013); “if policy and disaster relief creates dependencies” (IPCC 2014a citing Wenzel 2009 and Fernández-Giménez et al. 2012); “in circumstances of inadequate entitlements, rights, and inequality” (IPCC 2014a 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 2014a citing Forbes 2007) (IPCC 2014a). Lack of involvement in formal government decision-making over resources also decreases the resilience of indigenous peoples and their cultures to climate change impacts (IPCC 2014a citing Ellemor 2005, Brown 2009, Finucane 2009, Turner and Clifton 2009, Sánchez-Cortés and Chavero 2011, and Maldonado et al. 2013).

Climate change can increase migration due to extreme events or long-term environmental changes. Much of the literature reviewed in the IPCC *Special Report on Extreme Events* 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 2014a). Major extreme weather events have in the past led to significant population displacement (IPCC 2014a). However, following rapid-onset events such as floods or storms, such displacement is usually short-term (Brzoska and Frohlich 2015). Most displaced people try to return to their original residence and rebuild as soon as circumstances allow (IPCC 2014a). As a result, only a portion of displacement leads to permanent migration (IPCC 2014a citing Foresight 2011 and Hallegatte 2012). Long-term changes in climate conditions such as droughts or land degradation have greater potential to result in permanent migration (Brzoska and Frohlich 2015).

A number of studies have found that migrants can face increased risks due to climate change impacts in their new destinations, such as in cities (IPCC 2014a citing Black et al. 2011). 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 (DOD 2015, NRC 2011c). Displacement affects human security by affecting housing, health, and economic outcomes (IPCC 2014a citing Adams et al. 2009 and Hori and Shafer 2010). A large influx of migrants can also encourage violence, especially if the refugees differ from the native population in ethnicity, nationality, and/or religion; have had previous conflicts with the receiving area; or want to settle long term (Brzoska and Frohlich 2015). In other cases, migration to more prosperous and resource-rich areas can dissolve conflicts (Brzoska and Frohlich 2015).

Conversely, 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 2014a citing Paul 2005). As migration is resource-intensive, in some cases migration flows decreased when the households had limited resources, such as in drought years (IPCC 2014a citing Findley 1994, van der Geest 2011, and Henry et al. 2004). Often, 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 2014a citing Warner and Afifi 2013).

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 (Schleussner et al. 2016, Buhaug et al. 2015, IPCC 2014a). 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 2014a citing Bernauer et al. 2012, Koubi et al. 2012, Scheffran et al. 2012, and Theisen et al. 2013). Many studies, however, argue that reduced availability and changes in the distribution of water, food, and arable land from a changing climate are factors prone to triggering violent conflicts (Brzoska and Frohlich 2015 citing Hsiang et al. 2013). Rather than a causal relationship between climate change and conflict, climate change is identified as a "threat multiplier" that exacerbates existing or arising threats to stability and peace and may trigger armed conflict (Buhaug 2016 citing CNA 2007). 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 2014a 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 2014a).

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 U.S. Department of Defense (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).

Climate change can compromise state integrity by affecting critical infrastructure, threatening territorial integrity, and increasing geopolitical rivalry (IPCC 2014a). 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 2014a). 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, 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 2014a citing Hanson et al. 2011, Nicholls et al. 2011, Barnett and Adger 2003, and Houghton et al. 2010). These changes can also have negative implications for navigation safety, port facilities, and coastal military bases (DOD 2015). Open access to resources and new shipping routes due to significant reductions in Arctic sea ice coverage could increase security concerns because of territorial and maritime disputes, if equitable arrangements between countries cannot be agreed to (DOD 2015, IPCC 2014a, GCRP 2014). A variety of maritime boundary disputes in the Arctic could be exacerbated by the increased accessibility of the region due to warmer temperatures (Smith and Stephenson 2013 citing Brigham 2011 and Elliot-Meisel 2009). Furthermore, nations bordering the Arctic maintain unresolved sea and economic zone disputes (Smith and Stephenson 2013 citing Liu and Kronbak 2010, Gerhardt et. al. 2010; NRC 2011b). Other transboundary impacts of climate change such as changing shared water resources and migration of fish stocks can increase geopolitical rivalry between countries (IPCC 2014a). Additionally, climate change could increase tension and instability over energy supplies (CNA Corporation 2014).

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 decision-making, increase their social and cultural resilience to climate change (IPCC 2014a). 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 2014a citing McLeman 2009). 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 2014a).

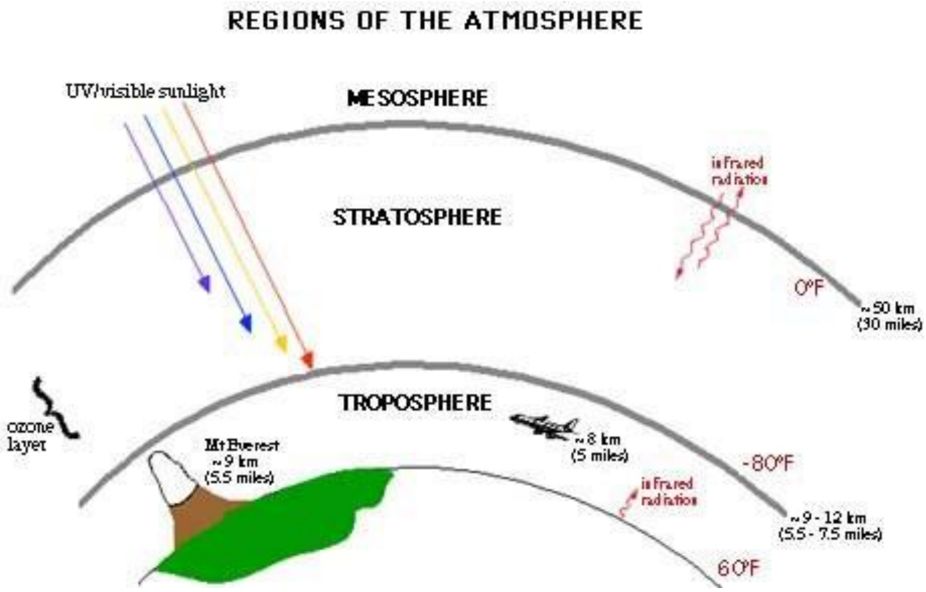
Local and traditional knowledge is a valuable source of information for adapting to climate change (IPCC 2014a, GCRP 2014). There is high agreement in the literature that the integration of local and traditional and scientific knowledge increases adaptive capacity (IPCC 2014a citing Kofinas et al. 2002, 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 be insufficient to respond to rapidly changing ecological conditions or unexpected or infrequent risks (IPCC 2014a, GCRP 2014). As a result, current traditional knowledge strategies could be inadequate to manage projected climate changes (IPCC 2014a citing Wittrock et al. 2011). 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 2014a).

Stratospheric Ozone

This section presents a review of stratospheric ozone and describes how CO_2 and climate change are projected to affect stratospheric ozone concentrations. 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).[23] This part of the atmosphere is 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 for humans and other organisms (Fahey and Hegglin 2011, Fahey et al. 2008, Figure 8.6.5-1).

[23] 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.

Figure 8.6.5-1. The Three Lowest Layers in Earth's Atmosphere and the Location of the Ozone Layer



Source: NOAA 2011
UV = ultraviolet; km = kilometers; °F – degrees Fahrenheit

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 from 220 to 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. Specifically, ozone is depleted in reactions that involve halogens, such as chlorine and bromine, which result from the decomposition of some halocarbons (GCRP 2017 citing WMO 2014). Alterations to the carbon cycle, including climate-driven ecosystem changes, influence atmospheric concentrations of CO_2 and methane. In turn, atmospheric aerosols affect clouds and precipitation rates, which change the removal rates, lifetimes, and abundance of the aerosols themselves (GCRP 2017 citing Nowack et al. 2015). Also, stratospheric ozone abundance can be affected by climate-driven circulation changes and longwave radiation feedbacks (GCRP 2017 citing Nowack et al. 2015).

IPCC reports it is *very likely* that anthropogenic contributions, particularly to GHGs and stratospheric ozone depletion, have led to the detectable tropospheric warming and related cooling in the lower stratosphere since 1961 (IPCC 2014a). Satellite and ground observations demonstrated clearly that stratospheric ozone was decreasing in the 1980s. There is an international consensus that human-made ozone-depleting substances (such as gases emitted by air conditioners and aerosol sprays) are responsible, which has prompted 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 2014a citing Correa et al. 2013).

Stratospheric ozone levels influence the surface climate in both the Northern and Southern Hemispheres. In the Northern Hemisphere, stratospheric ozone extremes over the Arctic contribute to spring surface temperatures, particularly linking low Arctic ozone in March with colder polar vortex and circulation anomalies (Ivy et al. 2017). March stratospheric ozone can be used as an indicator of spring climate in certain regions (Ivy et al. 2017). In the Southern Hemisphere, comparison of the 1979-2010 climate trends shows that stratospheric ozone depletion drives climate change (Li et al. 2016). Interactive chemistry causes cooling in the Antarctic lower stratosphere and acceleration of the circumpolar westerly winds (Li et al. 2016). In turn, this impacts overturning circulation in the Southern Ocean, leading to stronger ocean warming near the surface and increased ice melt around the Antarctic (Li et al. 2016). Changes in stratospheric ozone influence the climate by affecting the atmosphere's temperature structure and circulation patterns (Ravishankara et al. 2008). Conversely, climate change could aid in 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. Consequently, it slows the chemical reactions between stratospheric ozone and ozone-depleting substances, assisting in ozone recovery. Climate change could enhance atmospheric circulation patterns that affect stratospheric ozone concentrations, assisting in ozone recovery in the extra-tropics. However, for polar regions, cooling temperatures can increase winter polar stratospheric clouds, which are responsible for accelerated ozone depletion. In summary, reduced stratospheric ozone may contribute to climate change while climate change has been projected to have a direct impact on stratospheric ozone recovery, although there are large elements of uncertainty within these projections.

Human-Made Ozone-Depleting Substances and Other Trace Gases

Until the mid-1990s, stratospheric ozone concentrations had been declining in response to increasing concentrations of human-made ozone-depleting substances (WMO 2014). Since the year 2000, ozone has been slowly increasing in the upper stratosphere (Steinbrecht et al. 2017). Examples of ozone-depleting substances include chlorofluorocarbons and compounds containing chlorine and 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.

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 to protect and heal the ozone layer and rebuild the ozone hole.[24] 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 chlorofluorocarbons are potent GHGs; therefore, reducing the emissions of these gases also

[24] 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.

reduces radiative forcing and hence reduces the heating of the atmosphere. However, hydrofluorocarbons (HFCs) were not included in the Montreal Protocol. Evidence shows that HFCs could contribute to anthropogenic climate change and, in 2016, the Kigali Amendment to the Montreal Protocol introduced a treaty on managing and phasing out HFCs (Hurwitz et al. 2016).

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 by hydroxyl radicals in the stratosphere, it produces water and the methyl radical. 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.

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 a height of 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, Reader et al. 2013) because the dominant reactions responsible for ozone loss slow as temperatures cool. For example, ozone in the upper stratosphere is projected to increase by 15 to 20 percent under a doubled CO_2 environment (Fahey et al. 2008 citing Jonsson et al. 2004). In the lower stratosphere, where day-night energy transport plays an important role both within the stratosphere and between the troposphere and stratosphere, cooling temperatures have less influence on ozone concentrations (except in the polar regions). Since 1993, ozone in the lower stratosphere above the Arctic has been greatly affected by cooling temperatures, as cooling has led to an increase in polar stratospheric clouds (Fahey et al. 2008). Polar stratospheric clouds play a significant role in reducing ozone concentrations. Ozone in the lower stratosphere above the Antarctic does not demonstrate such a significant response to cooling temperatures because this region already experiences temperatures cold enough to produce these clouds.

Circulation and Transport Patterns

The large-scale Brewer-Dobson circulation represents the transport between the troposphere and stratosphere: an upward flux of air from the troposphere to the stratosphere occurs in the tropics balanced by a downward flux of air in the extratropics (the middle latitudes that extend beyond the tropics). This circulation carries stratospheric ozone from the tropics poleward. It is suggested that the ozone in the lower stratosphere has experienced an acceleration in this transport over the past century, 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). According to many chemistry-climate models and observational evidence, climate change is thought to accelerate the Brewer-Dobson circulation, thus extending the decline of ozone levels in the tropical lower stratosphere through the 21st century (WMO 2014).

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).[25] 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.

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 (WMO 2011, Pawson and Steinbrecht 2014). 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 2014). An updated study from 2000 to 2016 found that ozone increased in the upper stratosphere by about 1.5 percent per decade in the tropics and by 2.5 percent per decade in the mid latitudes (35 to 60 degrees) (Steinbrecht et al. 2017). From 2000 to 2016 in the lower stratosphere, the trends are not statistically significant (Steinbrecht et al. 2017). 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).

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. The model ensemble suggests the northern mid-latitudes total column ozone will recover to 1980 levels from 2015 to 2030, and the southern mid-latitudes total column ozone will recover from 2030 to 2040. Overall, the recovery of total ozone to 1980 levels in the mid-latitudes is projected to occur 10 to 30 years earlier because 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: increased formation of ozone in the mid-to-upper stratosphere in response to cooling temperatures, accelerated ground-level ozone formation in the troposphere as it warms, and an accelerated Brewer-Dobson circulation increase in ozone transport in the lower stratosphere from the tropics to the mid-latitudes (WMO 2014 citing 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 chlorofluorocarbons, CH_4, and N_2O by reducing their lifetime and increasing their removal from the atmosphere. In addition, this could increase the vertical

[25] 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).

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).

Compound Events

According to the IPCC, compound events consist of two or more extreme events occurring simultaneously or in sequence, the combination of one or more extreme events with underlying conditions that amplify the impact of the events, or combinations of events that are not themselves extremes but that collectively lead to extreme impacts when combined (IPCC 2012). While some compound events may involve individual components that cancel one another out, others may include components with additive or even multiplicative effects (GCRP 2017). Compound events can also have societal impacts even if they occur across separate regions; for example, droughts in multiple agricultural areas could have amplifying effects on food shortages (GCRP 2017).

The underlying probability of compound events occurring may increase because of climate change, as underlying climate variables shift (GCRP 2017). Examples of shifting underlying conditions that could contribute to compound event frequency or severity include higher temperatures (of both surface and sea), increased drought risk, increased overall precipitation, and changes to oceanic circulation patterns (Cook et al. 2015, GCRP 2017, Swain et al. 2016). Climate change could also facilitate the emergence of new types of compound events by combining previously unseen physical effects (GCRP 2017). An example of this is Hurricane Sandy, which was affected by sea-level rise, anomalously high temperatures, and a so-called “blocking ridge” on Greenland that routed the storm toward the mainland and may have been caused by reduced summer sea ice in the region (GCRP 2017).

Climactic extremes in opposite directions can also form harmful compound events when occurring in sequence. For example, two major livestock and agricultural die-off events in Mongolia occurred in 1999–2002 and 2009–2010 when summer drought was immediately followed by extreme cold and heavy snowfall (IPCC 2012 citing Batjargal et al. 2001). Overall impacts of these events in Mongolia included a 33 percent loss in livestock and a 40 percent reduction in gross agricultural output as compared to previous years (IPCC 2012).

The impact of climate change on the frequency and severity of compound events remains uncertain because many climate models only address certain aspects of the climate system and cannot forecast compound events that involve combined forces from different subsystems (GCRP 2017, AghaKouchak et al. 2014). This makes the risks posed by compound events to be undervalued in modeled estimates of future climate conditions (GCRP 2017, AghaKouchak et al. 2014 citing Gräler et al. 2013).

To the extent the Proposed Action and alternatives would increase the rate of CO_2 emissions relative to the No Action Alternative, they would contribute to the general increased risk of extreme compound events. While this rulemaking alone would not cause increases in compound event frequency and severity from climate change, it would be one of many global actions that, together, could heighten these effects.

Tipping Points and Abrupt Climate Change

Tipping points refer to thresholds within Earth systems that could be triggered by continued increases in the atmospheric concentration of GHGs, incremental increases in temperature, or other relatively small or gradual changes related to climate change. Earth systems that contain a tipping point exhibit large or accelerating changes or transitions to a new physical state, which are significantly different from the rates of change or states that have been exhibited in the past, when the tipping point is crossed. The following discussion provides examples of tipping points in Earth systems.

Atlantic Meridional Overturning Circulation (AMOC)

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, which transports oceanic heat from low to high latitudes. 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 (approximately 22,000 years ago) (Lenton et al. 2008 citing Stocker and Wright 1991). This is expected to 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 may slow global ocean circulation, leading to impacts on global climate and ocean currents. A 2015 study indicated that these effects are underway, finding that the AMOC has weakened since 1975 to a degree that is unprecedented in the past millennium (Rahmstorf et al. 2015).

IPCC reports it is *very likely* that the AMOC will weaken over the 21st century; further, it reports it is *likely* that there will be some decline in the AMOC by about 2050, but the AMOC could increase in some decades because of large natural internal variability (IPCC 2013b). IPCC also reports that it is *very unlikely* that the AMOC will undergo an abrupt transition or collapse in the 21st century (for the scenarios considered), and 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 2013b). However, IPCC (2013b) concludes that a collapse beyond the 21st century for large sustained warming cannot be excluded.

Greenland and West Antarctic Ice Sheets

The sustained mass loss by ice sheets would cause a significant increase in sea level, and some part of the mass loss might be irreversible (IPCC 2013b). 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 more than about 1°C (1.8°F) (*low confidence*) but less than about 4°C (7.2°F) (*medium confidence*) global mean warming with respect to preindustrial levels.

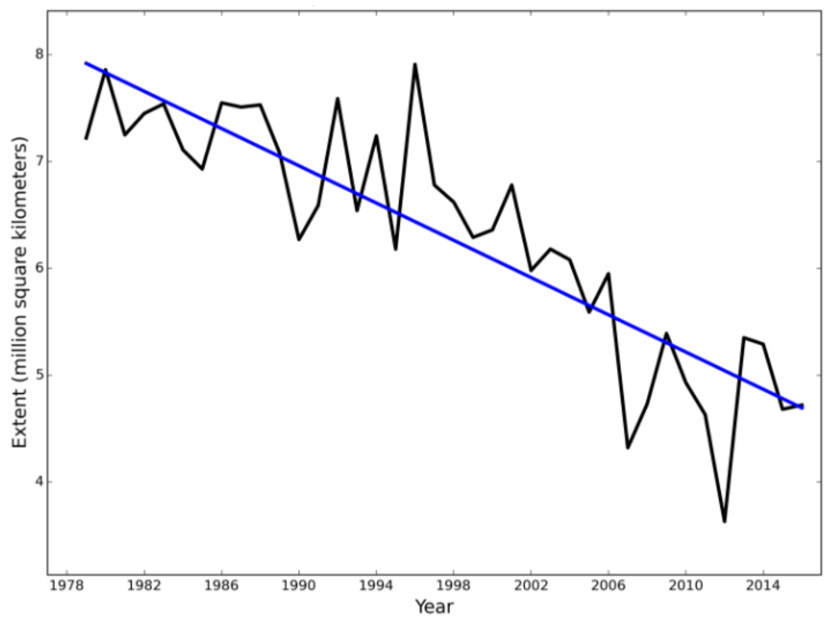
Of particular concern is the potential for abrupt increases in sea-level rise from rapid destabilization and ice loss from glaciers with bases in deep water. For these glaciers, warming oceans erode the base and cause the ice to float, accelerating losses. In Greenland, most areas of deep water contact between ice sheets and the ocean are limited to narrow troughs where the ice is less positioned 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 change is possible, but current evidence and understanding is insufficient to make a quantitative assessment (IPCC 2013b, NRC 2013b, Hansen et al. 2013). That said, two studies (Joughin et al. 2014, Rignot et al. 2014) published since the IPCC (2013a) assessment report indicate that West 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) demonstrates the potential irreversibility of marine-based ice sheet loss and the presence of thresholds beyond which ice loss becomes self-sustaining.

Arctic Sea Ice

Since satellite observations of Arctic sea ice began in 1978, a significant decline in the extent of summer sea ice 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 (Figure 8.6.5-2) (GCRP 2017). IPCC (2013b) suggests that anthropogenic influences have *very likely* contributed to these Arctic sea-ice losses since 1979, and that it is *very likely* that the Arctic sea-ice cover will continue to shrink and thin.

Figure 8.6.5-2. Average Monthly Arctic Sea-Ice Extent (September 1979–2016)[a]



Source: NSIDC 2016
[a] Ice extent for each September plotted as a time series based on the 1979 to 2016 data. The black line connects the ice extent data points and the trend line is plotted with a blue line.

Rising temperatures are reducing ice volume and surface extent on land, lakes, and sea, with this loss of ice expected to continue. 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 2017 citing IPCC 2013a and Snape and Forster 2014; NRC 2013b). 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 2013b).

Larger areas of open water in the Arctic during the summer will affect the Arctic climate, ecosystems, and human activities in the Northern Hemisphere; these impacts on the Arctic could potentially be large and irreversible. Less summer ice could 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).

Irreversibility of Anthropogenic Climate Change Resulting from Carbon Dioxide Emissions

A large fraction of anthropogenic climate change resulting from CO_2 emissions (e.g., global mean temperature increase, and a decrease in ocean pH) 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 2013b). Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. Because of the long time scales of heat transfer from the ocean surface to depth, ocean warming will continue for centuries (IPCC 2013a).

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):

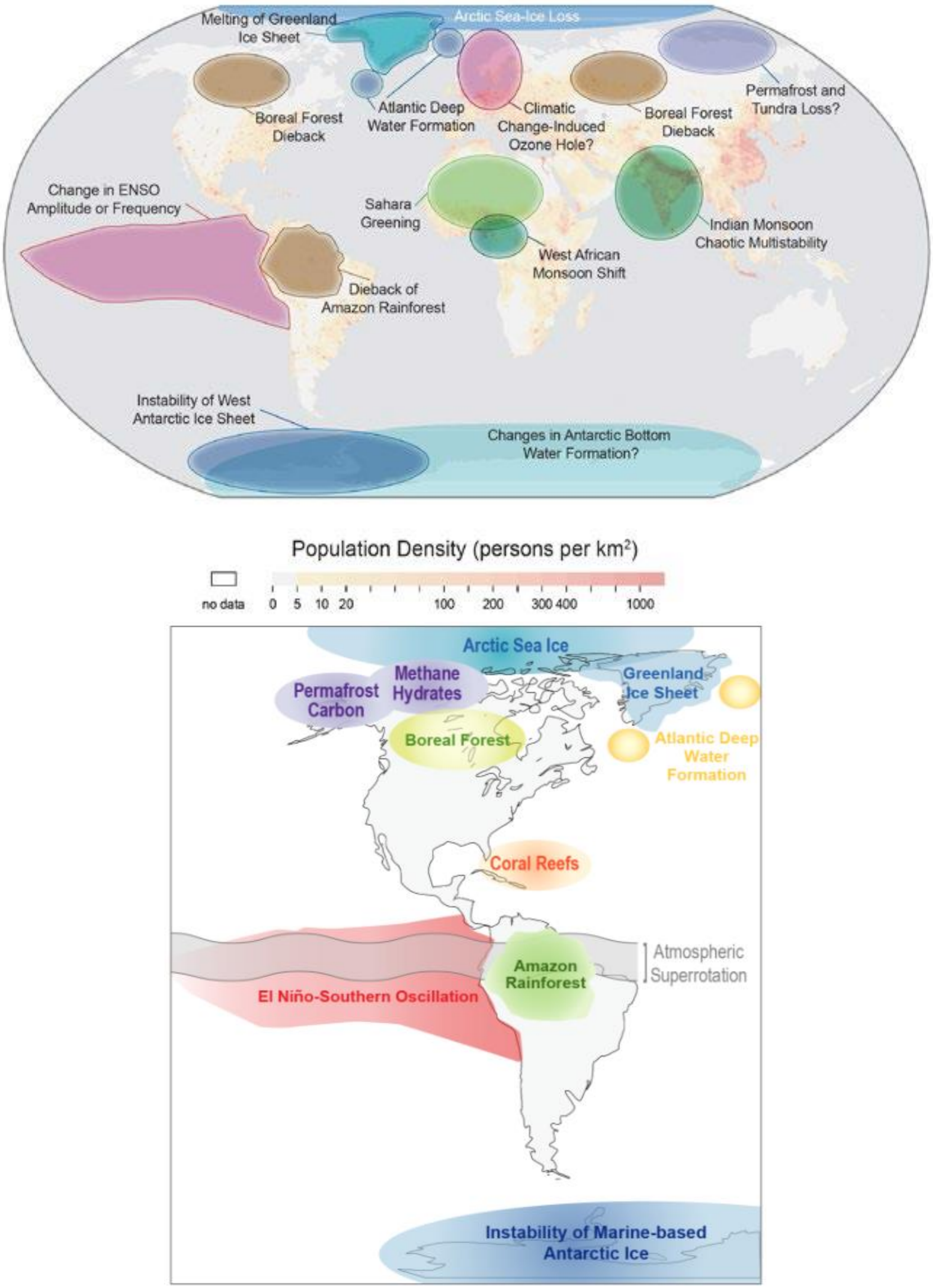
- Direct impacts from an abrupt event, such as flooding of an ecosystem through a combination of storm surge and sea-level rise.
- Incremental climatic changes that exceed a threshold beyond which a species enters decline, for example, pikas and ocean coral populations are close to physiological thermal limits.
- Adding stress to species in addition to nonclimatic 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 food webs after the decline of a keystone species.

It is expected that some species will become extinct or fall below viable numbers in the next few decades (NRC 2013b). IPCC states that there is *high confidence* that a large fraction of species faces increased extinction risk due to climate change during the 21st century and beyond (IPCC 2014a).

Additional Tipping Points

GCRP (2017) and NRC (2013b) indicate a number of other potential tipping points (Figure 8.6.5-3), which are described in this section.

Figure 8.6.5-3. Potential Tipping Points



Source: GCRP 2017 adapted from Lenton et al. 2008

El-Niño-Southern Oscillation (ENSO). It is *likely* that regional rainfall variability due to ENSO will increase over the 21st century; however, confidence in the amplitude and spatial pattern of ENSO remains low (IPCC 2013b). In the United States, the rainfall variability associated with ENSO events will *likely* move eastward in the future (IPCC 2013a).

Amazon rainforest. Deforestation, reductions in precipitation, a longer dry season, and increased summer temperature could contribute to accelerated forest dieback. Important additional stressors also include forest fires and human activity (such as land clearing) (Lenton et al. 2008). In general, studies agree that future climate change increases the risk of the tropical Amazon forest being replaced by seasonal forest or savannah (IPCC 2013a citing Huntingford et al. 2008, Jones et al., 2009, Malhi et al., 2009).

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). Models indicate that under a high emission scenario (RCP8.5), even without water stress, additional heat could transition the boreal forests into a net CO_2 source (Helbig et al. 2017).

Release of methane hydrates and permafrost and tundra loss. A catastrophic release of methane to the atmosphere from clathrate hydrates[26] in the seabed and permafrost, and from northern high-latitude and tropical wetlands, has been identified as a potential cause of abrupt climate change (GCRP 2017). The size of the methane hydrate reservoir in the arctic is estimated to be between 500 and 3,000 gigatons of carbon potentially being equivalent to 82,000 gigatons CO_2 (assuming the hydrates are released in that state) (GCRP 2017). However, uncertainty exists in the sensitivity of these carbon reservoirs—as measured by the rate of carbon release from stored hydrates per unit of warming—to a changing climate (Mestdagh et al. 2017). These reserves will probably not reach the atmosphere in sufficient quantity to affect climate significantly over the next century (GCRP 2017). Permafrost stores hold an additional estimated 1,300 to 1,600 gigatons of carbon, about 5 to 15 percent of which is vulnerable to being released in the coming century (GCRP 2017 citing Schuur et al. 2015). Past research warns that these tundra sources could cause an abrupt release of carbon, causing dramatic warming in the atmosphere (Hansen et al. 2013, NRC 2013b), but more recent literature suggests that the most probable process is a gradual and prolonged release of carbon (Schuur et al. 2015, Mestdagh et al. 2017). These estimates of a slow emissions rate from permafrost and hydrates may be incorrect if anthropogenic GHG emissions cause the Earth to warm at a faster rate than anticipated (GCRP 2017).

To the extent that the Proposed Action and alternatives would increase the rate of CO_2 emissions relative to the No Action Alternative, they could contribute to the marginal increase or acceleration of reaching these tipping-point thresholds. Moreover, while this rulemaking alone would not cause CO_2 emissions to reach the tipping-point thresholds, it would be one of many global actions that, together, could contribute to abrupt and severe climate change.

[26] 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 (GCRP 2014 citing Brook et al. 2008).

8.6.5.3 Regional Impacts of Climate Change

In response to the MY 2017–2025 CAFE Standards Draft EIS, NHTSA received a public comment on Section 9.3.2.1 noting that, "with regard to climate change, regional impacts are likely to be particularly relevant to the public." The comment further encouraged NHTSA to include regional models and information contained in state or regional assessments for each region of the U.S. to illustrate how changes in transportation-related GHG emissions can influence regional climate impacts. In addressing the health, societal, and environmental impacts of climate change in the MY 2017–2025 CAFE Standards Final EIS (NHTSA 2012) and in the Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS (NHTSA 2016c), NHTSA included a qualitative assessment of the regional impacts of climate change.

NHTSA recognizes the public's interest in understanding the potential regional impacts of climate change; these impacts are discussed at length in panel-reviewed synthesis and assessment reports from IPCC (at the continent scale), and GCRP (at the U.S. regional scale). In addition to including this material in NHTSA's prior EISs, the Third and Fourth National Climate Assessments (GCRP 2014, GCRP 2017) provide this very regional analysis, reporting observations and projections for climatic factors (GCRP 2017), and the regional and sectoral impacts of climate change (Section 8.6.5.2, *Sectoral Impacts of Climate Change*) for each region of the United States (GCRP 2014). The regions addressed in the Third National Climate Assessment (GCRP 2014) include Alaska, Coasts, Great Plains, Hawaii and Pacific Islands, Midwest, Northeast, Northwest, Oceans, Southeast and Caribbean, and Southwest.

In the NEPA context, there are limits to the utility of drawing from assessments to characterize the regional climate impacts of the Proposed Action and alternatives. The existing assessment reports do not have the resolution necessary to illustrate the effects of this action, because they typically assess climate change impacts associated with emission scenarios that have much larger differences in emissions—generally between one and two orders of magnitude greater than the difference between the No Action Alternative in 2100 and the emissions increases associated with all the action alternatives in 2100. The differences between the climate change impacts of the Proposed Action and alternatives are far too small to address quantitatively in terms of their impacts on the specific resources of each region. Attempting to do so may introduce uncertainties at the same magnitude or more than the projected change itself (i.e., the projected change in regional impacts would be within the noise of the model). Agencies' responsibilities under NEPA involve presenting impacts information that would be useful, relevant to the decision, and meaningful to decision-makers and the public.

For a qualitative review of the projected impacts of climate change on regions of the United States, readers may consult Section 5.5.2 of the MY 2017–2025 CAFE Standards Final EIS (NHTSA 2012), Section 5.5.2 of the Phase 2 Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Final EIS (NHTSA 2016c), and the Third and Fourth National Climate Assessments (GCRP 2014, GCRP 2017). These assessments demonstrate that the impacts of climate change vary at the regional and local level, including in strength, directionality (particularly for precipitation), and particularity. These variations reflect the unique environments of each region, the differing properties of the sectors and resources across regions, the complexity of climatic forces, and the varied degrees of human adaptation across the United States. However, the overall trends and impacts across the United States for each climate parameter and resource area are consistent with the trends and impacts described in Section 8.6.5.2, *Sectoral Impacts of Climate Change.* Because the Proposed Action and alternatives are projected to result in only very minor increases in global CO_2 concentrations and associated impacts, including changes in temperature, precipitation, sea level, and ocean pH, as compared to the No Action

Alternative, the climate impacts projected in those reports would be expected to increase only to a marginal degree.

CHAPTER 9 MITIGATION

CEQ regulations implementing NEPA require that the discussion of alternatives in an EIS "[i]nclude appropriate mitigation measures not already included in the proposed action or alternatives."[1] An EIS should discuss the "[m]eans to mitigate adverse environmental impacts."[2] As defined in the CEQ regulations, mitigation includes the following actions:[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. This chapter provides an overview of the impacts associated with the Proposed Action and alternatives (Section 9.1, *Overview of Impacts*) and then discusses potential mitigation measures that would reduce those impacts (Section 9.2. *Mitigation Measures*). The chapter also addresses those impacts that would remain after mitigation (Section 9.3, *Unavoidable Adverse Impacts*), short-term commitments of resources and implications for long-term productivity (Section 9.4, *Short-Term Uses and Long-Term Productivity*), and commitments of resources to comply with the standards (Section 9.5, *Irreversible and Irretrievable Commitments of Resources*).

9.1 Overview of Impacts

Compared to the No Action Alternative, the Proposed Action and alternatives would increase fuel consumption and greenhouse gas (GHG) emissions. As seen in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, the Proposed Action and alternatives would marginally increase the impacts of climate change that would otherwise occur under the No Action Alternative. As reported in Chapter 4, *Air Quality*, aggregate emissions of most criteria air pollutants (with the exception of carbon monoxide) are generally anticipated to increase while aggregate emissions of most hazardous air pollutants (with the exception of diesel particulate matter) are generally expected to decrease under the Proposed Action and alternatives as compared to the No Action Alternative. Compared to the No Action Alternative, health effects are estimated to increase under the Proposed Action and alternatives for all analysis years (Chapter 4, *Air Quality*). Nationally, for those pollutant emissions projected to increase under the Proposed Action and alternatives, there would be a slight decrease in the rate of reduction otherwise achieved by implementation of Clean Air Act (CAA) emissions standards for criteria pollutants and toxic air pollutants. Conversely, for those pollutant emissions projected to decrease under the Proposed

[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 Council*, 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).

Action and alternatives, there would be a slight increase in the rate of reduction otherwise achieved through CAA emissions standards. Some nonattainment areas in the United States could experience emissions de creases for some pollutants under certain alternatives and analysis years, while other areas could experience increases. These differences are attributed to the complex interactions between tailpipe emission rates of the various vehicle types, the technologies NHTSA assumes manufacturers will incorporate to comply with the standards, upstream emissions rates, the relative proportion of gasoline and diesel in total fuel consumption, and changes in vehicle miles traveled (VMT) from the rebound effect.

9.2 Mitigation Measures

CEQ regulations concerning mitigation refer to mitigation measures that the lead agency can include to mitigate potential adverse impacts. In this case, NHTSA does not have the jurisdiction to regulate the specified pollutants that are projected to increase as a result of the Proposed Action and alternatives. The potential negative impacts of the Proposed Action and alternatives, however, could be mitigated through other means by other federal, state, or local agencies. Examples of mitigation measures include further EPA emissions standards for passenger cars and light trucks, incentives for the purchase of more fuel efficient vehicles, mechanisms to encourage the reduction of VMT (such as increases in public transportation or economic incentives similar to increased taxation on fuel consumption), and funding to provide air filtration for residences adjacent to highways.

9.3 Unavoidable Adverse Impacts

As demonstrated in Chapter 3, *Energy*, and Chapter 4, *Air Quality*, the Proposed Action and alternatives are projected to result in an increase in energy consumption, an increase in most criteria pollutant emissions, and a reduction in most hazardous air pollutant emissions, compared to the No Action Alternative. Although decreases in VMT under the Proposed Action and alternatives as compared to the No Action Alternative are anticipated, these VMT decreases would be offset by the decreases in fuel economy associated with the Proposed Action and alternatives, resulting in a net increase in energy consumption and a net increase in some pollutant emissions compared to the No Action Alternative. Increases in some pollutant emissions could also have additional adverse impacts on human health; thus, overall U.S. health impacts associated with air quality (mortality, asthma, bronchitis, emergency room visits, and work-loss days) are anticipated to increase across the Proposed Action and alternatives as compared to the No Action Alternative. These increases in energy consumption, pollutant emissions, and human health impacts are not unavoidable adverse impacts, however, as they could be offset by emissions regulations, changes in consumer behavior (e.g., changing driving patterns or increased consumer demand for EVs), fluctuations in the energy market, or other future activities.

As discussed in Chapter 5, *Greenhouse Gas Emissions and Climate Change*, certain impacts, such as increased global mean surface temperature, sea-level rise, and increased precipitation, could occur because of accumulated total GHG emissions in Earth’s atmosphere. These impacts could be further exacerbated to a very small degree under the Proposed Action and alternatives as compared to the No Action Alternative. As described in Section 5.4, *Environmental Consequences,* the Proposed Action and alternatives would increase GHG emissions compared to the No Action Alternative, thereby marginally increasing anticipated climate change impacts.

9.4 Short-Term Uses and Long-Term Productivity

The Proposed Action and alternatives would result in an increase in crude oil consumption and a marginal increase in GHG emissions (and associated climate change impacts) compared to the No Action Alternative. To meet the proposed standards, manufacturers may apply various fuel-saving technologies during the production of passenger cars and light trucks. NHTSA cannot predict with certainty which specific technologies and materials manufacturers would apply or in what order. Some vehicle manufacturers may commit additional resources to existing, redeveloped, or new production facilities to meet the standards, although NHTSA cannot predict with certitude what actions manufacturers may take. For further discussion of the costs and benefits of the proposed rule, consult NHTSA's Preliminary Regulatory Impact Analysis (PRIA).

9.5 Irreversible and Irretrievable Commitments of Resources

As noted, some vehicle manufacturers may commit additional resources to existing, redeveloped, or new production facilities to meet the fuel economy 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 proposed standards would depend on the technologies and materials manufacturers select.

CHAPTER 10 LIST OF PREPARERS AND REVIEWERS

10.1 U.S. Department of Transportation

Table 10-1 identifies the preparers, contributors, and reviewers in the U.S. Department of Transportation.

Table 10-1. U.S. Department of Transportation Preparers and Reviewers

Preparers	
Kenneth Katz, Contracting Officer's Representative, NHTSA	
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	26 years of experience in transportation energy, alternative fuels and emissions analysis and rulemaking; 18 years of experience in fuel economy rulemaking
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Hannah Fish, Attorney Advisor, NHTSA	
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10.2 Consultant Team

ICF supported NHTSA in preparing its environmental analyses and this environmental impact statement. Table 10-2 identifies the consultant team and their contributions.

Table 10-2. Consultant Team

Project Management	
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	B.S., Environmental Science, University of Ulster at Coleraine, Northern Ireland 16 years of experience in the environmental field and 13 years of experience in the management, preparation, and review of NEPA documents
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Robert Greene, Project Coordinator	
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CHAPTER 11 DISTRIBUTION LIST

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- Argonne National Laboratory
- Armed Forces Retirement Home, Campus Operations
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- Central Intelligence Agency, Headquarters Environmental Safety Staff
- Committee for Purchase From People Who Are Blind or Severely Disabled
- Consumer Product Safety Commission, Directorate for Economic Analysis
- Defense Nuclear Facilities Safety Board
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- Denali Commission
- Executive Office of the President, Council on Environmental Quality
- Executive Office of the President, Office of Science and Technology Policy
- Export-Import Bank of the United States, Office of the General Counsel
- Farm Credit Administration, Office of Regulatory Policy
- Federal Communications Commission, Office of General Counsel
- Federal Communications Commission, Wireless Telecommunications Commission, Competition and Infrastructure Policy Division
- Federal Deposit Insurance Corporation, Corporate Services Branch, Administration Division, Health, Safety and Environmental Programs Unit
- Federal Energy Regulatory Commission, Office of Energy Projects
- Federal Maritime Commission
- Federal Trade Commission, Litigation
- General Services Administration, Federal Permitting Improvement Streering Council
- General Services Administration, Public Buildings Service, Office of Facilities Management
- International Boundary and Water Commission, U.S. & Mexico, Environmental Management
- International Trade Commission
- Marine Mammal Commission
- Millennium Challenge Corporation
- National Aeronautics and Space Administration, Environmental Management Division, Office of Strategic Infrastructure

- National Capital Planning Commission, Office of Urban Design and Plan Review Division
- National Credit Union Administration, Office of General Counsel, Division of Operations
- National Endowment for the Arts
- National Indian Gaming Commission, Contracts Division
- National Science Foundation, Office of the General Counsel
- Nuclear Regulatory Commission, Division of Decommissioning, Uranium Recovery, and Waste Programs
- Nuclear Regulatory Commission, Division of Fuel Cycle Safety, Safeguards, and Environmental Review
- Nuclear Regulatory Commission, Office of New Reactors, T7 F03M, Division of Site and Environmental Reviews
- Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Division of License Renewal
- Oak Ridge National Laboratory
- Overseas Private Investment Corporation, Environmental Affairs Department
- Presidio Trust, NEPA Compliance
- Securities and Exchange Commission, Office of Support Operations
- Small Business Administration, Office of the General Counsel, Department of Litigation & Claims
- Social Security Administration, Office of Environmental Health and Occupational Safety
- Tennessee Valley Authority, Environmental Policy and Planning
- U.S. Agency for International Development
- U.S. Department of Agriculture, Agriculture Research Service, Natural Resources and Sustainable Agricultural Systems
- U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Environmental Services
- U.S. Department of Agriculture, Farm Service Agency
- U.S. Department of Agriculture, National Institute of Food and Agriculture, Natural Resources and Environmental Unit
- U.S. Department of Agriculture, Natural Resources Conservation Service, Ecological Services Division
- U.S. Department of Agriculture, 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, First Responder Network Authority (FirstNet)
- U.S. Department of Commerce, National Oceanic and Atmospheric Administration
- U.S. Department of Defense, Army Corps of Engineers, Office of the Assistant Secretary of the Army, Civil Works
- U.S. Department of Defense, Army Corps of Engineers, Planning and Policy Division

- U.S. Department of Defense, Defense Logistics Agency; DLA Installation Support, Environmental Management
- U.S. Department of Defense, Department of Air Force, NEPA Center
- 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
- U.S. Department of Defense, Department of Navy, Office of the Deputy Assistant Secretary of the Navy Environmental Planning and Terrestrial Resources
- U.S. Department of Defense, Missile Defense Agency, Facilities, Military Construction, and Environmental Management Directorate, Environmental Management Division
- U.S. Department of Defense, National Guard Bureau
- U.S. Department of Defense, National Guard Bureau, Environmental Programs Division, Assessments and Evaluation Branch (NEPA)
- U.S. Department of Defense, National Security Agency
- U.S. Department of Defense, Office of the Deputy Assistant Secretary of Defense, Environment, Safety, and Occupational Health
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- U.S. Department of Defense, U.S. Marine Corps
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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
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- 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 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, Immigration and Customs Enforcement
- U.S. Department of Homeland Security, Transportation Security Administration
- U.S. Department of Homeland Security, U.S. Citizenship and Immigration Services, Facilities Management Division, Planning, Programming & Environmental Branch
- 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 Housing and Urban Development, Office of Environment and Energy
- U.S. Department of Interior, Bureau of Indian Affairs, Division of Environmental and Cultural Resources Management
- 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 Office of Environmental Programs, Division of Environmental Assessment
- U.S. Department of Interior, Bureau of Reclamation
- U.S. Department of Interior, Bureau of Safety and Environmental Enforcement, Environmental Compliance Division
- U.S. Department of Interior, National Park Service, Environmental Planning and Compliance Branch
- U.S. Department of Interior, Office of Environmental Policy and Compliance
- U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement
- U.S. Department of Interior, U.S. Fish and Wildlife Service, Ecological Services, Branch of Conservation Planning Assistance
- U.S. Department of Interior, U.S. Geological Survey—Environmental Management Branch
- U.S. Department of Interior, U.S. Geological Survey, Office of Water Program Coordination
- 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, Federal Bureau of Investigation
- U.S. Department of Justice, Federal Bureau of Investigation, Occupational Safety & Environmental Programs Unit
- U.S. Department of Justice, Federal Bureau of Prisons, Site Selection and Environmental Review Branch
- U.S. Department of Justice, U.S. Marshals Service, Office of General Counsel
- U.S. Department of Justice, U.S. Marshals Service, Office of Security, Safety, and Health
- U.S. Department of Labor, Office of the Assistant Secretary for Administration and Management
- 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 Transportation, Federal Aviation Administration
- U.S. Department of Transportation, Federal Highway Administration
- 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, Environmental and Corridor Planning
- U.S. Department of Transportation, Federal Transit Administration, Office of Environmental Programs

- U.S. Department of Transportation, Maritime Administration
- U.S. Department of Transportation, Office of the Secretary of Transportation, Office of Policy Development, Strategic Planning, and Performance
- U.S. Department of Transportation, Office of the General Counsel
- U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, Hazardous Materials Safety
- 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, Volpe Center, Environmental Science and Engineering
- U.S. Department of Transportation, Volpe Center, Organizational Performance Division
- U.S. Department of the Treasury, CDFI Fund
- U.S. Department of the Treasury, Office of Environment, Safety, and Health
- U.S. Department of Veterans Affairs, Green Management Program Service
- U.S. Department of Veterans Affairs, Office of Construction and Facilities Management
- U.S. Department of Veterans Affairs, Veterans Health Administration, Office of General Counsel
- U.S. Environmental Protection Agency
- U.S. Environmental Protection Agency, Office of Federal Activities
- U.S. Postal Service, Environmental Compliance/Risk Management

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
- 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
- Missouri Federal Assistance Clearinghouse, Office of Administration, Commissioner's Office
- 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 Kay Ivey, 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 John Carney, 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 Eric Holcomb, Governor of Indiana
- The Honorable Kim Reynolds, Governor of Iowa
- The Honorable Jeff Colyer, 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 Michael L. Parson, 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 Chris Sununu, Governor of New Hampshire
- The Honorable Phil Murphy, Governor of New Jersey
- The Honorable Susana Martinez, Governor of New Mexico
- The Honorable Andrew Cuomo, Governor of New York
- The Honorable Roy Cooper, Governor of North Carolina
- The Honorable Doug Burgum, 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 Ricardo Rosselló, Governor of Puerto Rico
- The Honorable Gina Raimondo, Governor of Rhode Island
- The Honorable Henry McMaster, 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 Phil Scott, Governor of Vermont
- The Honorable Ralph Northam, Governor of Virginia
- The Honorable Jay Inslee, Governor of Washington
- The Honorable Jim Justice, 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 Tribe of Texas
- Alabama-Quassarte Tribal Town
- Alatna Village
- Algaaciq Native Village (St. Mary's)
- Allakaket Village
- Alturas Indian Rancheria, California
- 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, Montana
- 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 Montana
- 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, South Dakota
- Chickahominy Indian Tribe, Inc.
- 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, Montana
- 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, South Dakota
- 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
- Iqurmuit Traditional Council
- Ivanof 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 in Kansas
- Kickapoo Tribe of Oklahoma
- King Island Native Community
- King Salmon Tribe
- Kiowa Tribe
- 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 Michigan
- 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, South Dakota
- 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, Michigan
- Nulato Village
- Nunakauyarmiut Tribe
- Oglala Sioux Tribe
- Ohkay Owingeh
- Omaha Tribe of Nebraska
- Oneida Nation of New York
- Oneida Nation
- 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 Minnesota
- Pueblo of Acoma
- Pueblo of Cochiti
- Pueblo of Isleta
- Pueblo of Jemez
- Pueblo of Laguna
- Pueblo of Nambe
- Pueblo of Picuris
- Pueblo of Pojoaque
- Pueblo of San Felipe
- Pueblo of San Ildefonso

- Pueblo of Sandia
- Pueblo of Santa Ana
- Pueblo of Santa Clara
- Pueblo of 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, California
- Rosebud Sioux Tribe of the Rosebud Indian Reservation, South Dakota
- 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, South Dakota
- 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, North Dakota
- 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 Manufacturers

- Accubuilt, Inc.
- Adient plc
- Adrian Steel Company
- Advanced Wheels of Technology, Inc.
- Adventurer LP
- Advics North America, Inc.
- AGC Glass Company North America
- Agility Fuel Systems
- Aisin World Corp. of America
- Akron Brass Company
- Alcoa Inc.
- Alliance Tire Americas, Inc.
- Almared, Inc.
- American Grease Stick Company
- American Honda Motor Co.
- American Kenda Rubber Industrial Company
- American Pacific Industries, Inc.
- American Powersports Mfg. Co. Inc.

- American Suzuki Motor Corporation
- Aston Martin Laginda
- Aston Martin The Americas
- ATI Performance Products, Inc.
- Auto Pro USA, Inc.
- Autoliv, Inc.
- Automobili Lamborghini
- Automobili Lamborghini America LLC
- Autotech Accessories Inc.
- Azure Dynamics Corporation
- B&W Custom Truck Beds, Inc.
- Battery-Biz Inc.
- Beijing Capital Tyre Co., LTD
- Bentley Motors, Inc.
- BF1 Systems Limited
- Bluecar SAS
- BMW of North America, LLC
- Bombardier Recreational Products Inc.
- Brake Parts Inc.
- Brammo, Inc.
- Bridgestone Americas Tire Operations, LLC
- Bugatti
- Buy4easy Inc
- Campagna Motors
- Carrier Corporation
- Centric Parts
- Cequent Consumer Products, Inc.
- China Manufacturers Alliance, LLC
- Chrysler (Fiat Chrysler Automobiles US LLC)
- CIRCOR Aerospace, Inc.
- Cleanfuel USA
- Clore Automotive, LLC
- Continental Automotive Systems, Inc.
- Continental Tire the Americas, LLC.
- Cooper Tire & Rubber Co.
- Craftsmen Industries, Inc.
- Daimler AG
- Daimler Trucks North America

- Daimler Vans USA, LLC
- Dana Driveshaft Manufacturing, LLC
- Daystar Products International, Inc.
- DDT Mobility Inc.
- Delphi Automotive Systems, LLC
- Discount Tire
- Dometic Corporation
- Dorman Products, Inc.
- Double Coin Holdings, Ltd.
- Ducati North America
- Duruxx LLC
- Dynamic Tire Corp.
- Eaton Corporation
- Eldorado Mobility Inc
- Emcara Gas Development Inc.
- e-ride Industries
- EV-Charge America Ltd
- Federal Coach, LLC
- Federal-Mogul Corporation
- Ferrari North America, Inc.
- Fisker Automotive Inc.
- Flex-a-lite
- Ford Motor Company
- Fram Group Operations, LLC
- Freedom Motors, Inc.
- General Motors, LLC
- GITI Tire (USA) Ltd.
- Goodyear Tire & Rubber Company
- Guardian Industries Corp.
- Hankook Tire America Corp.
- Hercules Tire & Rubber Company
- Holley Performance Products, Inc
- Honda North America, Inc.
- Hydraulic Supply Co.
- Hyundai Kia America Technical Center Inc.
- Hyundai Motor America
- ILJIN USA Corporation
- Isuzu Manufacturing Services of America

- Isuzu Motors America, LLC
- Isuzu Technical Center of America, Inc.
- Jaguar Land Rover North America, LLC
- Karma Automotive LLC
- Kia Motors America
- Koenigsegg Automotive AB
- Kraco Enterprises, LLC
- Kumho Tire U.S.A., Inc.
- Landi Renzo USA
- Lionshead Specialty Tire & Wheel LLC
- LiquidMetal Motorsports, Inc.
- LiquidSpring LLC
- Lotus Cars USA, Inc.
- Mack Trucks
- Maserati North America, Inc.
- Maxion Wheels/Hayes Lemmerz
- Mazda Motor Corp.
- Mazda North American Operations
- McLaren Automotive Incorporated
- Mercedes-Benz USA, LLC
- Michelin North America, Inc.
- Midway Specialty Vehicles
- Mitsubishi Motors North America, Inc.
- Mobility Ventures LLC
- Morgan 3 Wheeler Limited
- Nissan North America, Inc.
- Nissens North America, Inc.
- Nitto Tire U.S.A. Inc.
- Norgren Inc.
- Oreion Motors LLC.
- Pagani Automobili SpA
- Pirelli Tire LLC
- Polaris Industries, Inc.
- Porsche Cars North America, Inc.
- Prime-Time Specialty Vehicles
- PT Multistrada Arah Sarana, Tbk
- Robert Bosch LLC
- Rolls-Royce Motor Cars, Ltd.

- Saab Cars North America, Inc.
- Sentech, Inc.
- Shandong Jinyu Industrial Co. Ltd.
- SKF USA Inc.
- Spartan Motors, Inc.
- Stoneridge Inc.
- Subaru of America, Inc.
- Sumitomo Rubber Industries, Ltd.
- Sumitomo Rubber USA, LLC
- Suzuki Motor of America, Inc.
- Tesla Motors, Inc.
- TI Group Automotive Systems, LLC
- Timken Company
- Tireco Inc.
- Tishomingo Acquisition, LLC
- Tong Yang Industry Co.
- Toyo Tire Holdings of Americas Inc.
- Toyota Motor Engineering & Manufacturing
- Toyota Motor North America, Inc.
- Tread Systems, Inc., dba Diamond Back
- Valeo
- Vantage Mobility International, LLC
- Vee Tyre and Rubber Co., Ltd.
- Vision Wheel, Inc.
- Vogue Tyre & Rubber Co.
- Volkswagen Group of America, Inc.
- Volvo Car USA LLC
- Volvo Group North America
- Wells Vehicle Electronics, L.P.
- Westward Industries
- Wheel Pros, LLC
- Wilson Manifolds Inc
- Yokohama Tire Corporation
- ZF North America, Inc.

11.6 Stakeholders

A notification of Draft EIS availability with a link to the website posting was sent to the project mailing list, which includes approximately 33 individuals who commented on the Notice of Intent in addition to the following organizations.

- AAA Mid-Atlantic
- Acadia Center
- Advanced Engine Systems Institute
- Alaska Public Interest Research Group
- Alliance of Automobile Manufacturers
- Alliance of Idle Mitigation Technologies
- Alliance to Save Energy
- Aluminum Association
- American Association of Blacks in Energy
- American Automotive Policy Council
- American Chemistry Council
- American Council for an Energy-Efficient Economy
- American Council on Renewable Energy
- American Fuel & Petrochemical Manufacturers
- 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 Petroleum Institute
- American Powersports Mfg. Co. Inc.
- American Road & Transportation Builders Association (ARTBA)
- American Security Project
- Appalachian Mountain Club
- Arizona Public Interest Research Group
- Association of Global Automakers
- Association of International Automobile Manufacturers, Inc.
- Association of Metropolitan Planning Organizations
- Auto Research Center
- BlueGreen Alliance
- BMore Indivisible
- Border Valley Trading LTD

- Boyden Gray & Associates PLLC
- Bridgestone Americas Tire Operations Product Development Group
- California Air Pollution Control Officers Association
- CALPIRG (Public Interest Research Group)
- CALSTART
- Cato Institute
- Center for Auto Safety
- Center for Biological Diversity
- Center for Energy Efficiency and Renewable Technologies
- Central States Air Resources Agencies
- Ceres and the Investor Network on Climate Risk (INCR)
- ChargePoint, Inc.
- Chesapeake Bay Foundation
- Citizens' Utility Board of Oregon
- Clean Air Task Force
- Clean Fuel Development Coalition
- Clean Power Campaign
- Commission for Environmental Cooperation
- Competitive Enterprise Institute
- Conservation Law Foundation
- Consumer Action
- Consumer Assistance Council of Cape Cod
- Consumer Federation of America
- Consumer Federation of the Southeast
- Consumers for Auto Reliability and Safety
- Consumers Union
- Con-way Inc
- Criterion Economics, L.L.C.
- Crowell Moring
- CSRA
- Dale Kardos & Associates, Inc.
- Dallas Clean Energy LLC
- Dana Holding Corporation
- Dana Incorporated
- Defenders of Wildlife
- Ecology Center
- Edison Electric Institute
- Electric Applications Inc.

- Electric Power Research Institute
- Empire State Consumer Association
- Engine Manufacturers Association
- Environment America
- Environment Illinois
- Environmental Defense Fund
- Environmental Law & Policy Center
- Evangelical Environmental Network
- Evangelical Lutheran Church in America
- FedEx Corporation
- Florida Consumer Action Network
- Florida Power & Light Co.
- Friends Committee on National Legislation
- Gibson, Dunn & Crutcher LLP
- Global Automakers
- Greater Washington Interfaith Power and Light
- Growth Energy
- HayDay Farms, Inc
- Honeywell Transportation Systems
- ICM
- IdleAir
- Illinois Trucking Association
- Illnois Public Interest Research Group
- Indiana University
- Institute for Policy Integrity at New York University School of Law
- Insurance Institute for Highway Safety
- International Council on Clean Transportation
- Jewish Community Relations Council
- Justice and Witness Ministries
- Kirkland & Ellis LLP
- Manufacturers of Emission Controls Association
- Maryknoll Office of Global Concerns
- Maryland Consumer Rights Coalition
- Maryland Public Interest Research Group
- Massachusetts Consumers Council
- Massachussetts Public Interest Research Group
- Mercatus Center, George Mason University
- Metro 4/SESARM

- Michigan Tech University
- Mid-Atlantic Regional Air Management Association, Inc.
- Motor & Equipment Manufacturers Association
- National Alliance of Forest Owners
- National Association of Attorneys General
- National Association of Clean Air Agencies
- 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 Coalition for Advanced Transportation
- National Conference of State Legislatures
- National Council of Churches USA
- National Governors Association
- National Groundwater Association
- National League of Cities
- National Propane Gas Association
- National Truck Equipment Association
- National Wildlife Federation
- Natural Gas Vehicles (NGV) America
- Natural Resources Canada
- Natural Resources Defense Council
- New Jersey Citizen Action
- New Mexico Public Interest Research Group
- NGVAmerica
- Northeast States for Coordinated Air Use Management
- Novation Analytics
- NTEA - The Association for the Work Truck Industry
- NY Public Interest Research Group
- Ozone Transport Commission
- Pearson Fuels
- Pew Environment Group
- Pierobon & Partners
- Plastics Industry Association
- Podesta Group

- Pollution Probe
- Presbyterian Church (USA)
- Public Citizen
- Reason Foundation and Strata Policy
- Recreation Vehicle Industry Association
- Renewable Fuels Association
- Republicans for Environmental Protection
- Road Safe America
- Rocky Mountain Institute
- Rubber Manufacturers Association
- Safe Climate Campaign
- Santa Clara Pueblo
- SaviCorp, Inc.
- Securing America's Future Energy
- Sierra Club
- Socially Responsible Investing
- SUN DAY Campaign
- Susquehanna River Basin Commission
- Teamsters Joint Council 25
- Tetlin Village Council
- The Accord Group
- The Aluminium Association, Inc.
- The Council of State Governments
- The Environmental Council of the States
- The Episcopal Church
- The Hertz Corporation
- The Lee Auto Malls
- The Pew Charitable Trusts
- The Truman National Security Project
- The United Methodist Church General
- TIAX LLC
- Trillium Asset Management Corporation
- Truck Manufacturer's Association
- Tufts University
- U.S. Chamber of Commerce
- U.S. Conference of Mayors
- Union for Reform Judaism
- Union of Concerned Scientists

- 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
- U.S. Public Interest Research Group
- Utility Consumers Action Network
- Vermont Energy Investment Corporation
- Vermont Public Interest Research Group
- Victims Committee for Recall of Defective Vehicles
- Virginia Citizens Consumer Council
- VNG.co LLC
- 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

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